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OF THE

GEOLOGICAL SOCIETY

OF

AMERICA

VOL. I

W J McGEE, *Editor*

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1890

COUNCIL FOR 1890

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REGULAR PUBLICATIONS.

The Society issues a single serial publication entitled **Bulletin of the Geological Society of America.** This serial is made up of *proceedings* and *memoirs*, the former comprising the records of meetings, with abstracts and short papers, lists of Fellows, etc., and the latter comprising the longer papers accepted for publication. The matter is issued as soon as practicable after acceptance in covered brochures, which are distributed at once to Fellows and exchanges. Provision has not yet been made for sales.

Volume 1, covering the work of the Society from its organization to the end of 1889, is now complete. It comprises the following brochures:

IRREGULAR PUBLICATIONS.

In the interests of exact bibliography, the Society takes cognizance of publications issued either wholly or partly under its auspices. Each author of a memoir receives 30 copies, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the proceedings also are authorized to order any number of separate copies at a slight advance on cost of paper and presswork; but these separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of Volume 1 have been issued:

Editions uniform with the Brochures of the Bulletin.

Pages	1- 86— 30	copies.	February	19,	1890.
	87- 98—130	"	March	7,	"
	99-162— 80	"	"	26,	"
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*Special Editions.**

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	19- 23 — 50	"	"	13,	"	"	"
	23- 27 —250	"	"	12,	"	"	"
	27- 31 —200	"	"	13,	"	"	"

* Bearing the imprint [" From Bull. Geol. Soc. Am., Vol. 1."]
† Fractional pages sometimes included.

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	568–570	—100 "	"	27,	"	With "
	571–586	—100 "	"	28,	"	"

ERRATA.

All contributors to Volume 1 have been invited to send in errata found in their contributions, and the volume has been scanned with some care by the Editor. The following errata, deemed worthy of notice, have been detected:

Text.

Page 50,	line	24	from	top	; *for*	"ampitheatre"	*read*	amphitheatre.
51	"	5	"	bottom	"	"section"	"	section.
52	"	5	"	top	"	"besides"	"	beside.
59	"	2	"	bottom	"	"heen"	"	been.
76	"	6	"	top	; *transpose* "*b*" and "*s*."			
80	"	13	"	bottom ; *for*		"fig. 2"	*read*	fig. 1.
" plate 1 ; *the cuts should be transposed.*								
102,	line	7	from	bottom ; *for*		"R. S. McConnell"	*read*	R. G. McConnell.
112	"	7	"	top	"	"See page —"	"	See page 128.
127	"	11	"	bottom	"	"report of"	"	report to.
137	"	17	"	"	"	"North cape"	"	East cape.
152	"	16	"	"	"	"fine débris"	"	débris.
171	"	15	"	"	"	"Temiscamany"	"	Temiscaming.
181	"	4	"	"	"	"been raised"	"	been.
182	"	6	"	top	"	"contended"	"	have contended.
"	"	14	"	"	"	"is"	"	has been.
"	"	18	"	bottom	"	"do"	"	does.
184	"	4	"	top	"	"ares"	"	axes.
185	"	8	"	"	"	"have"	"	had.
192	"	12	"	"	"	"Harper"	"	Harker.
"	"	"	"	"	"	"Larn"	"	Sarn.
"	"	5	"	bottom	"	"xxxiv, 1878"	"	xliv, 1888.
247	"	8	"	top	"	"107° 30′"	"	117° 30′.
249, page-head title					"	"SEVENSON"	"	STEVENSON.
278,	line	20	from	bottom	"	"G. Eldridge"	"	G. H. Eldridge.
299	"	19	"	"	"	"La Ronge"	"	La Rouge.
313	"	4	"	top	"	"J. G. Hinde"	"	G. J. Hinde.
"	"	8	"	"	"	"	"	"
314	"	11	"	"	"	"Fielden"	"	Feilden.
"	"	2	"	bottom	"	"Proceedings Royal Dublin Society, 1878" *read* Scientific Proc. Roy. Dublin Soc., N. S., vol. II, 1880, pp. 43, 44.		

Page 315, line 17 from top	; *for*	"J. G. Hinde"	*read*	G. J. Hinde.
317, page-head title	"	"FAUNÆ"	"	FAUNA.
326, line 15 from top	"	"River Range"	"	River Rouge.
330 " 14 " "	"	"*plestocenicum*"	"	*pleistocenicum*.
334 " 8 " "	"	"Leda river"	"	Roseau river.
335 " 5 " bottom	"	"Verrazzani"	"	Verrazani.
337 " 10 " "	"	"*curva*"	"	*curta*.
" " 9 " "	"	"*parallella*"	"	*parallela*.
342 " 8 " "	"	"river"	"	Mississippi.
344 " 17 " "	"	"Slay-slates"	"	Clay-slates.
348 " 6 " "	"	"*curvatus*"	"	*incurva*.
367 " 1 " "	"	"71–72"	"	71–22.
399 " 1 " "	"	"R. S. McConnell"	"	R. G. McConnell.
401, page-head title	"	"ID"	"	IN.
405, line 13 from top	"	"vallay"	"	valley.
" " 21 " "	"	"high"	"	wide.
452 " 3 " bottom	"	"J. R. Woodworth"	"	J. B. Woodworth.
494 " 10 " "	"	"p. 485"	"	p. 486.
495 " 6 " "	"	"*mesacostalis*"	"	*mesocostalis*.
500 " 17 " top	"	" "	"	"
501 " 3 " bottom	"	"Ezra Brainard"	"	Ezra Brainerd.
506 " 19 " "	"	"axes"	"	axis.
507 " 3 " "	"	"base of *B*"	"	base of *D*.
509 " 18 " "	"	"1843"	"	1847.
513 " 9 " "	"	"Brainard"	"	Brainerd.
525 " 6 " "	"	"Herr"	"	Heer.
526 " 18 " "	"	"	"	"
541 " 9 " "	"	"Makcenzie"	"	Mackenzie.
545, page-head title	"	"C. F. WRIGHT"	"	G. F. WRIGHT.
549 line 2 from bottom	"	"orming"	"	forming.

Covers.

Page 203, line 3 from top	; *for*	"Rock"	*read*	Rocks.
287 " 2 " "	"	"pp. 237–310"	"	pp. 287–310.
" " 6 " "	"	"Society"	"	Survey.
501 " 6 " "	"	"Ezra Brainard	"	Ezra Brainerd.
" " 6 " "	"	"Henry M. Seeley"	*read*	Henry M. Seely.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 1, PP. 1-86, PL. 1 FEBRUARY 15, 1890

ORGANIZATION OF THE GEOLOGICAL SOCIETY OF AMERICA

PROCEEDINGS OF THE SEMI-ANNUAL MEETING HELD AT TORONTO, AUGUST 28-29, 1889

PAPERS READ AT THE TORONTO MEETING

J. J. STEVENSON, *Secretary*

CONTENTS

ORGANIZATION OF THE GEOLOGICAL SOCIETY OF AMERICA.

HISTORICAL SKETCH OF THE ORGANIZATION.*

Geological science early assumed, in America, the form of organized activity. Various societies of local scope were initiated in the early part of

* Prepared by Prof. Alexander Winchell, in accordance with the request of the Council.

the present century; but the first which was destined for permanence was the Association of American Geologists, which first convened at Philadelphia, on the second of April, 1840. Meetings were held in 1840, 1841, and 1842, the proceedings of which were published, in 1843, in a volume entitled "Transactions of the Association of American Geologists and Naturalists." The inclusion of "Naturalists" had been determined in 1843. The number of members was seventy-seven. Meetings were also held annually until 1847. The "Transactions" were published in the American Journal of Science for the corresponding years. In 1847 it was voted to resolve the organization into "The American Association for the Advancement of Science." In such capacity it assembled in Philadelphia, September 20, 1848. Thus the "American Association" was, in its incipiency, a body of geologists, and its first Constitution was prepared by the geologists assembled in Boston, in 1847. After the creation of the broader organization, geology shared with the other sciences such facilities as the Association afforded, and on the last reorganization it was recognized (with Geography) as Section E. With the numerical growth of the Association, the multiplication of its sections, the expanding volume of its proceedings, the increasing amount of its general business, and the diminished opportunities for scientific work, it began to be felt that the aims of American geology might perhaps be better served by a return to the original status. The question was held under informal consideration for several years.

The first open movement for an independent organization was made by the geologists assembled at the meeting of the American Association at Cincinnati, in 1881. A committee was appointed to consider the advisability of the project and take requisite preparatory steps. Professor N. H. Winchell was chairman, and Professor C. H. Hitchcock secretary of the committee, but no published records preserve the names of the other members. Circulars were issued by the committee, and one hundred and twenty-six answers were received, all but two of which favored the organization of a separate society. The committee reported to Section E at the Montreal Meeting of the Association, in 1882. It was there voted expedient to establish a geological magazine. A proposed constitution for a society was presented, discussed, and laid on the table for future consideration. Some hesitation was manifest on the part of some of the older members who had not participated in the earlier proceedings. It was suggested, on one hand, that Section E of the Association offered all the advantages of a geological society, and on the other it was alleged that the requirements of Canadian geologists were met by the recently organized Royal Society of Canada. It was also suggested that the formation of a separate society might conflict with the interests of the American Association. The whole subject, therefore, was laid over to a subsequent occasion. At the Minneapolis Meeting of the Association, in

1883, the consideration of the magazine and the society was resumed; but little was accomplished beyond the appointment of a committee to confer with the Mineralogical and Geological Section of the Philadelphia Academy of Natural Sciences. For various reasons the subject was not discussed at the Philadelphia Meeting of the Association in 1884, at the Ann Arbor Meeting in 1885, or at the Buffalo Meeting in 1886. Meantime the necessity of a separate geological organization became more apparent, and some who were at first indifferent began to express a desire that further steps be taken. At the New York Meeting, in 1887, no action was taken by Section E, but the American Committee of the International Congress, which existed under the sanction of the American Association, adopted the following resolution: "That the American Committee of the International Congress will approve of a call for the meeting of an American Geological Congress, whose object shall be the discussion of important geological questions."

In accordance with the judgment of American geologists present at the Montreal Meeting, that it was "expedient to establish a geological magazine," an association of seven geologists, representing different portions of the country, began, on the first of January, 1888, the publication of the "American Geologist," a monthly periodical, with editorial management fixed provisionally at Minneapolis. In the June number of this periodical appeared, from the chairman and secretary of the committee which had been constituted at Cincinnati in 1881, a call "upon all geologists" to assemble at Cleveland, on the day preceding the opening of the Meeting of the American Association, for the purpose of organizing, if deemed expedient, a national geological society. The basis of organization suggested in this circular restricted membership in the contemplated society to the members and fellows of the American Association, and devolved on the Association the election of the president and secretary of the new society. It was also contemplated that the permission of the Association should be asked for Section E "to hold meetings at such time and place as they may desire."

Promptly on August 14, 1888, in pursuance of the published call, the geologists in attendance at Cleveland assembled for the purpose of discussing the organization of a national society. Alexander Winchell was chosen chairman and Julius Pohlman secretary. It was at once apparent that interest in the proposed organization amounted to zeal. It was unanimously resolved that an American Geological Society was now desirable. As to the relation which it should sustain to Section E of the American Association, different views were expressed; but they were speedily harmonized. It had often been urged as an objection to the projected Society, that it might impair attendance at the meetings of the American Association. With a view to avoiding all conflict, it was suggested, on one hand, that the membership of the society should be coextensive with that of Section E, and on

the other, that its officers should be the same as those chosen for Section E. Some, with more zeal for the interests of geology than for those of the Association, advocated complete independence. Both ends were reached by a compromise which provided that the original members of the Geological Society must be active workers or teachers of geology, who were either members or fellows of the Association; but that, after January 1, 1889, other persons would be eligible. The compromise further provided that a summer meeting should always be held at the same time and place as the meeting of the Association; but the business meeting of the society was to be during the winter holidays. The meeting pronounced in favor of publication, and, with this view, an annual assessment of ten dollars. A committee was appointed to draft a constitution to be presented at an adjourned meeting on the following day. The committee consisted of Alexander Winchell, of Ann Arbor, chairman; J. J. Stevenson, of New York, secretary; Edward Orton, of Columbus; Charles H. Hitchcock, of Hanover; and J. R. Procter, of Frankfort.

At the adjourned meeting, August 15, the committee presented the form of a provisional constitution which, with slight changes, was adopted. As to membership, meetings, and fees it embodied the instructions of the earlier meeting; and, beyond this, contained only the usual provisions for name, officers, and amendments, and a clause providing for going into effect. The same committee was continued, with instructions to give the requisite attention to the completion of the organization.

It is noticeable that the action at Cleveland was not undertaken by Section E, but by American geologists, in pursuance of a call addressed to "all American geologists." Nor did the plan of organization contemplate restricting the Society to persons connected with the Association. It is thus in no way subordinate to Section E, nor to the Association, though it proposes to hold an annual meeting conjointly with the Association. It possesses complete autonomy, and requires no sanction from the Association in its attempt to represent the interests of American geology.

Thirty-seven eligible persons subscribed to the constitution before the adjournment of the Association. Immediately after adjournment the committee of organization resumed its efforts, and by November 1 more than one hundred names had been obtained, and the first meeting was promptly called to assemble at Ithaca, under the hospitality of Cornell University. An informal conference was held on the afternoon and evening of December 26, and at 10 a. m., December 27, the formal meeting convened in the hall of Sage College. The attendance was small, but it was well understood that the attendance was not an exponent of the deep and general interest felt in the movement. The meeting was called to order and presided over by the chairman of the organizing committee. In a preliminary statement made

by the committee, it appeared that 137 persons had given their adhesion to the Society, of whom 70 were fellows of the American Association, 45 were members, and 22 were not connected with the Association. Of the 112 "original fellows," 89 had paid their fees, and during the progress of the day this number was raised to 98. On a canvass of the ballots returned through the mails to the organizing committee, it appeared that 22 others had been elected, who, by the constitution, would become active fellows after January 1, 1889.

When the meeting proceeded to the election of officers, it was agreed that candidates standing highest on the nominating ballots returned through the mails should constitute a ticket. On duly balloting, the board of officers was found elected as follows:

JAMES HALL, Albany, *President.*
JAMES D. DANA, New Haven,
ALEXANDER WINCHELL, Ann Arbor, } *Vice-Presidents.*
J. J. STEVENSON, New York, *Secretary.*
H. S. WILLIAMS, Ithaca, *Treasurer.*
J. W. POWELL, Washington,
J. S. NEWBERRY, New York, } *Members-at-large of the Council.*
C. H. HITCHCOCK, Hanover,

The foregoing Board, elected under the provisional constitution, formed the Council for 1889.

A committee was chosen by ballot for reporting a revision of the constitution. This consisted of Alexander Winchell, H. S. Williams, J. J. Stevenson, H. L. Fairchild, and C. H. Hitchcock. The subject of publication remained, by the constitution, under the discretion of the Council; but an advisory committee was now appointed for the purpose of offering recommendations to the Council. This consisted of Joseph LeConte, of Berkeley, California; W J McGee, of Washington (Secretary); I. C. White, of Morgantown, West Virginia; N. H. Winchell, of Minneapolis, and W. M. Davis, of Cambridge.

The name of the society was discussed, and, though fixed by the constitution for the present as "American Geological Society," it was generally agreed that a preferable title would be THE GEOLOGICAL SOCIETY OF AMERICA. It was also formally agreed that fellowship in the society should be indicated by the initials "F. G. S. A.," and it was recommended that this title be employed on all suitable occasions.

It was finally voted that the Secretary should prepare a report of the meeting, to be printed in pamphlet form for distribution to the fellows and others, but it was distinctly provided that this should not stand as "No 1" of the recognized publications of the society. The form and style of publication remained to be fixed by the Council and advisory committee.

At the close of the business, the chairman called upon the President-elect to address the Society. Professor Hall, the veteran American geologist, still in the possession of abundant vigor, ascended the platform, and in an address of thirty minutes tendered the Society thanks, congratulations, counsel, and a reference to historic events stretching over a period of fifty years. His choice as first President of the Society he considered as the greatest honor of his life. The organization of a distinct geological society was something he had long desired and long expected. It was the working geologists of America who formed the first nucleus, around which had grown up the bulky organization of the American Association. For many years the Association proved of great service to geology, but he had felt, for some years past, that younger men were becoming so numerous that the day had arrived for the pioneers to stand back. At the same time the popular character of the Association had rendered it somewhat an undesirable arena in which to introduce the results of the profounder labors of geological investigation. He counseled harmony and mutual forbearance. He understood what provocations sometimes arise. He had sometimes himself yielded to them, and had always thereafter suffered regrets. New circumstances present ever new provocations; but he hoped every American geologist would be mentally prepared to pursue a course of justice, and, if need be, of forbearance and conciliation, in order that peace and harmony may reign throughout our ranks. The President's remarks were exceedingly well received, and produced an excellent impression.

In the evening a reunion was held at the private residence of Professor H. S. Williams, where a brilliant and accomplished hostess, with her aids, rounded off delightfully the graver occupations of the day.

The Geological Society thus began its existence strong in numbers, ability and finances. It had already enlisted the adhesion of almost every working geologist in the United States, and none unworthy had been permitted to enter. Thus was established again an authoritative representative of American geology, competent to know what the interests of American geology demand, and with full liberty to act from motives lying exclusively within its own field. May peace and a spirit of mutual consideration, sympathy, and helpfulness reign within its borders. May the wise counsels of its first President remain as a testament to guide the footsteps of many generations in the ways of usefulness and honor.

CONSTITUTION.

ARTICLE I.—NAME.

This Society shall be called THE AMERICAN GEOLOGICAL SOCIETY.

ARTICLE II.—OBJECT.

The object of this Society shall be the promotion of the science of Geology in North America.

ARTICLE III.—FELLOWS.

1. The original Fellows shall be working Geologists and Teachers of Geology who are now members of the American Association for the Advancement of Science, who signify their acceptance of Fellowship and pay the required fee before January 1, 1889.

2. Subsequently to January 1, 1889, all working Geologists and Teachers of Geology in North America will be eligible to Fellowship, and will become Fellows on signifying their acceptance of election and paying the required fee within three months after notice of election.

3. Election to Fellowship shall be effected by means of correspondence; and an affirmative vote of three-fourths of all Fellows voting shall be necessary to constitute an election.

ARTICLE IV.—OFFICERS.

1. The officers of the Society shall be a President, two Vice-Presidents, a Secretary, and a Treasurer, who, with three Fellows, shall form an Executive Council.

2. These shall be chosen annually by the Society at large.

3. The duties of these officers shall be those usually performed by officers thus named in scientific societies.

4. No Fellow shall hold the office of President or Vice-President for more than two years in succession.

5. The Executive Council shall determine the manner and material of all the publications, and shall have the responsible control of all the Society's work and property, except in so far as otherwise determined by this Constitution; they shall consider all nominations to Fellowship, and their ap-

proval shall be necessary before the submission of such nominations for vote of the Fellows; they shall call special meetings of the Society at such times and places as they shall determine; and shall arrange the programme of proceedings at all meetings; and shall perform such other duties as shall be, in their judgment, necessary for the prosperity of the Society and the promotion of Geological Science in North America.

6. These officers shall be elected in the first instance by the Fellows present at the first meeting held after this Constitution goes into effect.

Article V.—Meetings.

The annual meeting shall be held between Christmas and New Year, at a place to be designated by the Executive Council. At that meeting the result of elections of Fellows and officers shall be announced; and all the general business of the Society shall be transacted. A second meeting shall be held at the time and place of the annual meeting of the American Association for the Advancement of Science, the character of which shall be determined by the Executive Council. Special meetings can be called by the Executive Council.

Article VI.—Amendments.

This Constitution may be amended at any annual meeting by the vote of three-fourths (¾) of all the Fellows: *Provided*, that the amendment has been proposed by five (5) Fellows, and that notice has been sent to all the Fellows at least three months before the meeting.

Article VII.—Provision for Effect.

This Constitution shall go into effect when at least one hundred (100) persons shall have communicated their acceptance of Fellowship to the Secretary of the Organizing Committee.

BY-LAWS.

1. Dues.—Each Fellow shall pay to the Treasurer annually on or before the annual meeting the sum of ten (10) dollars. Any Fellow in arrears for two (2) years shall be stricken from the list, provided he shall have been informed of his deficiency a second time by the Secretary of the Society, after an interval of six (6) months.

2. Mode of Election.—The details of the election of officers and Fellows shall be left to the Executive Council.

3. Amendments.—These By-Laws may be amended at any annual meeting by vote of three-fourths (¾) of the Fellows present.

PROCEEDINGS OF MEETING FOR FINAL ORGANIZATION HELD AT ITHACA, NEW YORK, DECEMBER 27, 1888.

In accordance with the call of the Committee of Organization, appointed by an assemblage of geologists at Cleveland, Ohio, on August 14th, 1888, a meeting was held at Ithaca, New York, on December 27th, 1888, to complete the organization of the American Geological Society.

The meeting was held in the Botanical Hall of Cornell University, and was called to order at 10.30 a. m. by Prof. Alexander Winchell, Chairman of the Committee. The following Fellows were present:

H. L. FAIRCHILD, Rochester University, Rochester, N. Y.
JAMES HALL, State Museum, Albany, N. Y.
C. H. HITCHCOCK, Dartmouth College, Hanover, N. H.
J. F. KEMP, Cornell University, Ithaca, N. Y.
H. B. NASON, Rensselaer Polytechnic Institute, Troy, N. Y.
W J McGEE, United States Geological Survey.
J. J. STEVENSON, University of the City of New York.
I. C. WHITE, West Virginia University, Morgantown, W. Va.
H. S. WILLIAMS, Cornell University, Ithaca, N. Y.
J. F. WILLIAMS, Pratt Technical Institute, Brooklyn, N. Y.
S. G. WILLIAMS, Cornell University, Ithaca, N. Y.
ALEX. WINCHELL, Michigan University, Ann Arbor, Mich.
N. H. WINCHELL, University of Minnesota, Minneapolis, Minn.

The Chairman, Prof. A. Winchell, laid on the table copies of the circulars which had been issued, and addressed the meeting, detailing the work already done and making recommendations on behalf of the Committee.

The list of Original Fellows, numbering 98, who had already complied with the requirements of the Provisional Constitution, Art. III, Section 1, was read:

CHAS. ALBERT ASHBURNER, Penn Building, Pittsburgh, Pa.
GEORGE F. BECKER, United States Geological Survey, San Francisco, California.
JOHN C. BRANNER, State Geologist, Little Rock, Arkansas.
GARLAND C. BROADHEAD, Professor of Geology, University of Missouri, Columbia, Missouri.
SAMUEL CALVIN, Professor of Geology, State University of Iowa, Iowa City, Iowa.
T. C. CHAMBERLIN, President of Wisconsin University, Madison, Wis.
JAMES H. CHAPIN, Professor of Geology, St. Lawrence University. Post office address, Meriden, Conn.
WILLIAM B. CLARK, Instructor in Palæontology, Johns Hopkins University, Baltimore, Md.
EDW. W. CLAYPOLE, Professor of Natural Science, Buchtel College, Akron, Ohio.
JOHN COLLETT, lately State Geologist of Indiana, Indianapolis, Ind.

THEO. B. COMSTOCK, Professor of Mining Engineering, Illinois University, Champaign, Illinois.

GEO. H. COOK, State Geologist of New Jersey, Professor of Geology, Rutgers College, New Brunswick, N. J.

EDW. D. COPE, 2102 Pine Street, Philadelphia, Penn.

FRANCIS W. CRAGIN, Professor of Geology and Natural History, Washburn College, Topeka, Kansas.

ALBERT R. CRANDALL, Professor of Geology, Agricultural and Mechanical College of Kentucky, Lexington, Kentucky.

WILLIAM O. CROSBY, Assistant Professor of Mineralogy and Lithology, Massachusetts Institute of Technology, Boston, Mass.

MALCOLM H. CRUMP, Professor of Natural Science, Ogden College, Bowling Green, Kentucky.

HENRY P. CUSHING, 786 Prospect Street, Cleveland, Ohio.

JAMES D. DANA, Professor of Geology, Yale University, New Haven, Connecticut.

WILLIAM M. DAVIS, Professor of Physical Geography, Harvard University, Cambridge, Mass.

J. S. DILLER, United States Geological Survey, Washington, D. C.

W. B. DWIGHT, Professor of Natural History, Vassar College, Poughkeepsie, N. Y.

BENJAMIN K. EMERSON, Professor of Geology, Amherst College, Amherst, Mass.

SAMUEL F. EMMONS, United States Geological Survey, Washington, D. C.

HERMAN L. FAIRCHILD, Professor of Geology, Rochester University, Rochester, N. Y.

ALBERT E. FOOTE, 1223 Belmont Avenue, Philadelphia, Pa.

P. MAX FOSHAY, Beaver Falls, Pa.

PERSIFOR FRAZER, Professor of Chemistry, Franklin Institute, Drexel Building, Philadelphia, Pa.

HOMER T. FULLER, Professor of Geology, Worcester Polytechnic Institute, Worcester, Mass.

GROVE K. GILBERT, United States Geological Survey, Washington, D. C.

GEO. BIRD GRINNELL, 318 Broadway, New York.

WILLIAM F. E. GURLEY, Danville, Ill.

CHRISTOPHER W. HALL, Professor of Geology, University of Minnesota, Minneapolis, Minn.

JAMES HALL, State Geologist, State Museum, Albany, N. Y.

ERASMUS HAWORTH, Professor of Geology, Penn College, Oskaloosa, Iowa.

ROBERT HAY, United States Geological Survey, Box 162, Junction City, Kansas.

ANGELO HEILPRIN, Professor of Invertebrate Palæontology, Academy of Natural Science, Philadelphia, Pa.

LEWIS E. HICKS, Professor of Geology, University of Nebraska, Lincoln, Neb.

EUGENE W. HILGARD, Professor of Agriculture, University of California, Berkeley, California.

ROBERT T. HILL, Professor of Geology, University of Texas, Austin, Texas.

CHAS. H. HITCHCOCK, Professor of Geology, Dartmouth College, Hanover, N. H.

LEVI HOLBROOK, P. O. Box 536, New York City.

JOSEPH A. HOLMES, Professor of Geology, University of North Carolina, Chapel Hill, N. C.

HORACE C. HOVEY, 14 Park Street, Bridgeport, Conn.

EDWIN E. HOWELL, 18 College Avenue, Rochester, N. Y.

ALPHEUS HYATT, Boston Society of Natural History, Boston, Mass.

JOSEPH F. JAMES, Professor of Geology, Agricultural College, Maryland.
LAWRENCE C. JOHNSON, United States Geological Survey, Meridian, Miss.
JAMES F. KEMP, Assistant Professor of Geology and Mineralogy, Cornell University, Ithaca, N. Y.
GEORGE F. KUNZ, 402 Garden Street, Hoboken, N. J.
JOSEPH LE CONTE, Professor of Geology, University of California, Berkeley, Cal.
J. PETER LESLEY, State Geologist, 1008 Clinton Street, Philadelphia, Pa.
W J MCGEE, United States Geological Survey, Washington, D. C.
FREDERICK J. H. MERRILL, Fordham Heights, N. Y.
ALBRO D. MORRILL, Professor of Biology and Geology, Ohio University, Athens, Ohio.
FRANK L. NASON, Assistant, Geological Survey of New Jersey, New Brunswick, New Jersey.
HENRY B. NASON, Professor of Natural Sciences, Rensselaer Polytechnic Institute, Troy, N. Y.
PETER NEFF, Cleveland, Ohio.
JOHN S. NEWBERRY, Professor of Geology, Columbia College, New York City.
EDWARD ORTON, State Geologist, Professor of Geology, State University, Columbus, Ohio.
AMOS O. OSBORN, Waterville, Oneida Co., N. Y.
RICHARD OWEN, New Harmony, Indiana.
HORACE B. PATTON, Assistant Professor of Geology, Rutgers College, New Brunswick, N. J.
WILLIAM H. PETTEE, Professor of Mineralogy and Economic Geology, Michigan University, Ann Arbor, Mich.
FRANKLIN PLATT, 615 Walnut Street, Philadelphia, Pa.
J. W. POWELL, Director of United States Geological Survey, Washington, D. C.
CHAS. S. PROSSER, United States National Museum, Washington, D. C.
RAPHAEL PUMPELLY, United States Geological Survey, Newport, R. I.
ISRAEL C. RUSSELL, United States Geological Survey, Washington, D. C.
JAMES M. SAFFORD, State Geologist, Professor in Vanderbilt University, Nashville, Tenn.
ROLLIN D. SALISBURY, Professor of Geology, Beloit College, Beloit, Wis.
CHARLES SCHAEFFER, 1309 Arch Street, Philadelphia, Pa.
NATHANIEL S. SHALER, Professor of Geology, Harvard University, Cambridge, Mass.
FREDERIC W. SIMONDS, Professor of Geology and Biology, Arkansas Ind. University, Fayetteville, Ark.
EUGENE A. SMITH, State Geologist, Professor of Geology, University of Alabama, Alabama.
JOHN C. SMOCK, Assistant in charge of State Museum, Albany, N. Y.
JOSEPH W. SPENCER, Professor of Geology, University of Georgia, Athens, Georgia.
JOHN J. STEVENSON, Professor of Geology, University of the City of New York, N. Y.
WILLIAM E. TAYLOR, Teacher of Geology and Natural History, Nebraska State Normal School, Peru, Neb.
ASA S. TIFFANY, 901 West Fifth Street, Davenport, Iowa.
JAMES E. TODD, United States Geological Survey, Professor Natural Science, Tabor College, Tabor, Iowa.
HENRY W. TURNER, United States Geological Survey, San Francisco, California.

WARREN UPHAM, United States Geological Survey, 21 Newbury Street, Somerville, Mass.

CHARLES R. VAN HISE, United States Geological Survey, Professor Mining and Petrology, Wisconsin University, Madison, Wis.

A. W. VOGDES, Captain Fifth Artillery, Fort Hamilton, New York Harbor, N. Y.

M. E. WADSWORTH, State Geologist, Director of Michigan Mining School, Houghton, Michigan.

CHARLES D. WALCOTT, U. S. Geological Survey, Washington, D. C.

ISRAEL C. WHITE, Professor of Geology, West Virginia University, Morgantown, W. Va.

ROBERT P. WHITFIELD, Curator of Geology and Palæontology, American Museum of Natural History, Central Park, New York City.

EDWARD H. WILLIAMS, Jr., Professor of Mining Engineering and Geology, Lehigh University, Bethlehem, Penn.

GEORGE H. WILLIAMS, Professor of Inorganic Geology, Johns Hopkins University, Baltimore, Md.

HENRY S. WILLIAMS, Professor of Geology, Cornell University, Ithaca, N. Y.

J. FRANCIS WILLIAMS, Director of Technical Museum, Pratt Institute, Brooklyn, N. Y.

SAMUEL G. WILLIAMS, Professor at Cornell University, Ithaca, N. Y.

ALEXANDER WINCHELL, Professor of Geology, University of Michigan, Ann Arbor, Mich.

HORACE V. WINCHELL, Assistant, Minnesota Geological Survey, Minneapolis, Minn.

NEWTON H. WINCHELL, State Geologist and Professor in University of Minnesota, Minneapolis, Minn.

ARTHUR WINSLOW, Assistant, Geological Survey of Arkansas, Little Rock, Ark.

The Secretary (of the Committee of Organization, acting as Secretary of the meeting), reported that a scrutiny of the ballots, received by mail from seventy-four Fellows, showed the election of the following candidates for Fellowship under Art. III, Section 2:

WM. S. BAYLEY, Professor of Geology, Colby University, Waterville, Maine.

WM. P. BLAKE, Mill Rock, New Haven, Conn.

R. ELLSWORTH CALL, Professor of Natural Science, High School, Des Moines, Iowa.

R. W. ELLS, Geological Survey of Canada, Ottawa, Canada.

J. C. FALES, Professor of Natural History, Centre College, Danville, Ky.

WM. M. FONTAINE, Professor of Geology, University of Virginia.

A. C. GILL, Student in Petrography, Johns Hopkins University, Baltimore, Md.

EDW. GILPIN, Jr., Inspector of Mines, Halifax, Nova Scotia.

H. G. HANKS, lately State Mineralogist, San Francisco, Cal.

DAVID HONEYMAN, Provincial Geologist, Halifax, Nova Scotia.

E. V. D'INVILLIERS, 711 Walnut Street, Philadelphia, Pa.

A. W. JACKSON, Professor of Mineralogy, Petrography and Applied Geology, University of California, Berkeley, Cal.

JULES MARCOU, 42 Garden Street, Cambridge, Mass.

P. H. MELL, Jr., Professor of Geology, Alabama Technical Institute, Auburn, Ala.

G. P. MERRILL, Curator, United States National Museum, Washington, D. C.

JAMES E. MILLS, 2[illegible] Van Ness Avenue, San Francisco, Cal.

J. H. PERRY, Professor of Natural Sciences, High School, Worcester, Mass.

After a general discussion respecting the needs of the Society, a committee was chosen to prepare a revised constitution to be submitted at the next meeting of the Society. The committee consists of

ALEX. WINCHELL, Ann Arbor, Mich.
H. S. WILLIAMS, Ithaca, N. Y.
J. J. STEVENSON, New York City.
H. L. FAIRCHILD, Rochester, N. Y.
C. H. HITCHCOCK, Hanover, N. H.

Election of Officers for the year 1889 being next in order, the Secretary read the result of the balloting for preference as received by him from 72 Fellows, after which the Fellows present, in accordance with the Provisional Constitution, Art. IV, Sec. 6, cast their ballots with the following result:

President.—JAMES HALL, Albany, N. Y.
First Vice-President.—JAMES D. DANA, New Haven, Conn.
Second Vice-President.—ALEX. WINCHELL, Ann Arbor, Mich.
Secretary.—JOHN J. STEVENSON, New York City.

Pending the ballot for Treasurer, a recess was taken until 2.30 P. M. Balloting was resumed immediately after the recess, and resulted in the election of—

Treasurer.—HENRY S. WILLIAMS, Ithaca, N. Y.
Members-at-large of the Council.—JOHN S. NEWBERRY, New York City; J. W. POWELL, Washington, D. C.; CHARLES H. HITCHCOCK, Hanover, N. H.

Prof. Hall then took the chair, but owing to indisposition retired after a few remarks, and Vice-President Winchell presided until the session's close.

The names of seventeen candidates for election into the Society were presented and referred to the Executive Council.

The following additional By-law was adopted:

Fellows of this Society are authorized to append the letters F.G.S.A. to their names to indicate their membership in this Society.

And it was resolved, as the sense of the meeting, that Fellows of the Society should so use those letters.

The Secretary was instructed to print the proceedings of this meeting with a complete list of the Fellows, for distribution as a circular.

The following resolution was passed unanimously:

Resolved, That the Committee on Revision of the Constitution be requested to take into consideration the propriety of allowing all Fellows to vote by proxy when absent from meetings of the Society.

A general discussion ensued respecting the form and character of the Society's publications, and the Secretary was instructed to urge Fellows to send suggestions respecting this matter to the Committee on Revision of the

Constitution. A committee was appointed as advisory to the Executive Council in reference to the character of publications. It consists of—

JOSEPH LECONTE, Berkeley, Cal.
W J MCGEE, Washington, D. C.
N. H. WINCHELL, Minneapolis, Minn.
I. C. WHITE, Morgantown, W. Va.
W. M. DAVIS, Cambridge, Mass.

It was agreed that when the Society adjourn, it adjourn to meet at Toronto, on Wednesday, August 28, 1889, immediately after the adjournment of Section E of the American Association for the Advancement of Science.

The Treasurer was authorized to pay bills for current expenses on certification by the President and Secretary.

Addresses were made by President Hall and Vice-President Winchell. The thanks of the Society were tendered to Prof. H. S. Williams and the Trustees of Cornell University for their courtesy and hospitality.

The rough minutes were read and approved; after which the Society adjourned to meet at Toronto, on Wednesday, August 28, 1889.

PROCEEDINGS OF THE SEMI-ANNUAL MEETING HELD AT TORONTO, CANADA, AUGUST 28 *AND* 29, 1889.

The Society met in Toronto University, Toronto, Ontario, on August 28, at 12.30 p. m., pursuant to adjournment; Vice-President Alexander Winchell in the chair and 53 Fellows present.

The Secretary read the report of the Executive Council, which stated that the roll of the Society shows 175 Fellows, and that the Treasurer's report shows a balance of $1,649 in the treasury.

The special business before the meeting was the report of the committee appointed at Ithaca meeting to prepare a new Constitution; but as that committee was not ready to present its report, the Society took a recess until 3.30 p. m.

At that hour the Society came together again, President James Hall in the chair, and listened to the committee's draft of a new Constitution. The chairman of the committee, Prof. Alex. Winchell, asked for instructions respecting the insertion of a section authorizing voting by proxy. After a prolonged discussion the Society, on motion of Mr. Robert Hay, referred the whole matter to the committee with power.

Mr. W J McGee, Secretary of the Advisory Committee on Publication, appointed at the Ithaca meeting, exhibited copies of the report presented by that committee to the Executive Council of the Society. The Executive Council was requested to authorize the distribution of copies of the report to Fellows of the Society.

The Society then adjourned to meet on Thursday, the 29th inst., in the theatre of the Normal School, the use of which had been granted by the Hon. G. W. Ross, Minister of Public Instruction.

Session of Thursday, August 29.

The Society met at 10.30 a. m., on Thursday, in the theatre of the Normal School. The meeting was opened by the President, James Hall, who delivered the following address:

OPENING ADDRESS BY THE PRESIDENT.

Gentlemen of the American Geological Society:

It is now my duty to call you to order for the first business meeting of the Society, to listen to the reading of papers, a list of which is already before you. This occasion does not seem to me to offer the proper opportunity for making a formal address, but there may be a number of you present who

are not familiar with the history of the past forty or fifty years, and are not aware of the influence originally exercised by geologists in the organization of the American Association for the Advancement of Science, from which this Geological Society has lately emerged—*not originated*, for it was the primary integral part of that organization.

Without special reference at this time to an older geological society, organized, as I think from recollection, about the year 1824, and which ceased to exist a few years later, the first knowledge which I have of a national or general organization for the advancement of geological science, the pursuit of geological investigations, the harmonizing of opposing views held by different men, and thereby reaching some system of nomenclature upon which all could unite, was in 1840. At that time the geological surveys of Pennsylvania, New York, and Massachusetts, and of other States, were in progress. Upon going into the field we found that our previous knowledge and teachings in regard to the geology of the State of New York were far from correct, and were even valueless for leading to any general conclusions regarding the order or age of our geological formations. In this state of affairs it was natural that we should look about us for counsel and assistance to those engaged in similar work, and some of whom had been longer in the field than we had been. I would like to say in this place what I suppose is not known to a dozen people in the country, that with an earnest desire to procure the best available talent in the country, Governor Marcy offered the first position on the geological survey of New York (the State being divided into four districts) to Prof. Edward Hitchcock, in recognition of his services in geology. There was no sectional feeling at that time, as you will observe from this act. All the partizanship and rancour that may have existed among politicians were forgotten when the organization and interests of the geological survey came before the governor, and he appointed the men whom he believed to be best fitted for the positions and for bringing to the people the best results from the new work, without regard to locality or political affiliation. I mention this incidentally as a matter of interest historically.

Referring to our organization, we were afterwards informed that there had previously been some correspondence between Prof. Hitchcock and some other geologists in regard to forming a geological society or association for the discussion of geological questions. Without this knowledge, however, the subject of such an association was considered by the four geologists of New York in their semi-annual meetings, which were held for the discussion of questions arising in their own districts and their relations to the adjacent districts of their co-workers. Since our geological series extended into Pennsylvania on the one hand and into Massachusetts on the other, it was deemed very important that we should know something of the experience

and views of our colleagues and co-workers in these States. In furtherance of our plans, Mr. Vanuxem entered into correspondence with Prof. Henry D. Rogers, of Pennsylvania, and with Prof. Edward Hitchcock, of Massachusetts, with a view to forming an association of such American geologists as were then engaged in State geological surveys. This was the first and main object, although at the first meeting persons other than those engaged in geological surveys came into the Association.

This movement was the origin of the Association of American Geologists, organized, in 1840, for the purpose of discussing geological questions and coming to some harmonious views in regard to the relations of the geological formations we were then investigating, and thereby reaching some system of nomenclature upon which we could all agree, and through which we might bring the knowledge acquired before the public with some unity of purpose and expression. These were simply the objects we then had in view. Our meeting in Philadelphia, in April, 1840, resulted in a good deal of discussion which reached no result. That meeting however prepared the way for further work and further discussion upon the important questions before us. No conclusions were reached regarding uniformity of nomenclature; though some other questions of importance regarding the sequence and extent of certain rock formations were settled by the end of the third meeting, while others remained, and still remain, undetermined. In the mean time the State geologists in New York were required by law to publish their reports, and since no agreement had been reached with their neighbors they continued, for the most part, the use of the local names proposed in the annual reports. The Pennsylvania reports published at a later date adopted a different nomenclature. While, therefore, our original purpose was not fully accomplished, much good resulted from personal intercourse and our earnest discussions of the then unsettled questions which came before us.

At the end of three years (as I now recollect) the naturalists of the country desired to join with the association of geologists for similar purposes and for bringing before their colaborers and the public in the same manner the results of their investigations and for inviting discussion upon unsettled questions. The organization then became the Association of American Geologists and Naturalists, and retained that title till 1848. Afterwards the chemists and physicists, who had held aloof from the beginning, were willing to join with us, and the American Association of Geologists and Naturalists became the American Association for the Advancement of Science. This is simply the history of events without detail; and now after a career of forty-nine years, when the number of geologists has increased more than fifty-fold, we find that the time afforded for the discussion of important geological topics is quite inadequate, and it has become necessary that some other means

should be devised to provide for the disposal of the ever increasing number and importance of those questions beyond the limited time allotted to Section E in the meetings of our Association; for the work of the section, including geography and geology, is so great that it is compelled to leave many of its papers unread, and its discussions are often curtailed beyond what is desirable and important.

Therefore, without any other object or feeling than here stated, this American Geological Society has been formed; and I hope that every member of this organization will feel that while acting independently in the Geological Society he still owes allegiance to the American Association for the Advancement of Science. We can maintain our own Society, giving us more freedom to do good work for geology, and at the same time afford to give sufficient time, energy, and earnestness to Section E in the American Association, and show that the members have not lost their interest in the questions of geology coming before it, nor their desire to sustain it in its pristine vigor as one of the most prominent sections of the American Association.

And now, gentlemen, there is no need of my proceeding farther with this historical narration. I thought it proper to say something of it, believing that many of the younger members may not have given sufficient attention to the matter, and that it might be interesting to them to hear something of our origin and history and the manner in which we began our work nearly fifty years ago. At that time our entire Paleozoic series, in all its grandeur, remained, in the minds of most persons, a chaotic mass, almost without a recognized term to designate any of its members and entirely without any accepted nomenclature for the whole.

Professor James D. Dana then read a paper entitled:

AREAS OF CONTINENTAL PROGRESS IN NORTH AMERICA, AND THE INFLUENCE OF THE CONDITIONS OF THESE AREAS ON THE WORK CARRIED FORWARD WITHIN THEM.

Remarks upon Professor Dana's paper were made by Mr. C. D. Walcott and Professor James Hall. The paper will be found appended to the proceedings of this meeting.

Professor James Hall then presented two oral communications, the substance of which is contained in the following abstracts:

SOME SUGGESTIONS REGARDING THE SUB-DIVISION AND GROUPING OF THE SPECIES USUALLY INCLUDED UNDER THE GENERIC TERM ORTHIS, IN ACCORDANCE WITH EXTERNAL AND INTERNAL CHARACTERS AND MICROSCOPIC SHELL STRUCTURE.

BY JAMES HALL.

[*Abstract.*]

The writer is aware that several generic names have already been proposed for species usually arranged under the designation of *Orthis*. Recent investigators have found it necessary to make farther sub-division, and to propose new generic terms.

The following grouping of the species has been adopted by the writer for a long time, but no publication has been made. The seventy-four species which have been especially studied seem to be very naturally arranged under the sub-divisions proposed, and are submitted to the American Geological Society with the desire to elicit information and legitimate criticism.

Unfortunately the writer has not had access to the latest publications on the Brachiopoda which have appeared in Europe, and therefore he does not know how far Prof. Œhlert and others may have anticipated the suggestions embodied in this paper.

Number of species classified.	*Proposed sub-division of the genus Orthis.*
14	O. occidentalis group, (shell impunctate) Low. Cambrian—Clinton.
5	O. (Platystrophia) " (") Chazy—Clinton.
12	O. plicatella " (") Chazy—Niagara.
6	O. tricenaria " (") Chazy—Niagara.
16	O. testudinaria " (shell punctate) Chazy—Corniferous.
14	O. hybrida " (") Niagara—Up. Carb.
5	O. propinqua (Schizophoria) group, (shell punctate) Clinton—Carboniferous.
2	O. (Bilobites) (Dicoelosia) biloba group, (shell punctate) Niagara—L. Held.

Species which have been studied and placed under the proposed grouping 74
" to be studied and placed under the proposed grouping 100

Orthis occidentalis group. (Shell impunctate.)

O. Billingsi, Hartt	Lower Cambrian.
O. ? Pepina, Hall	Potsdam.
O. plicifera, “	Chazy.
O. borealis, Bill.	Trenton.
O. bellarugosa, Conrad	“ & Hudson River—Cincinnati group.
O. Maria, Bill.	“ “
O. sinuata, Hall	“ “
O. occidentalis, Hall	“ “
O. porcata, McCoy	“ “
O. retrorsa, Salter	“ “
O. Scovilli, S. A. Miller	“ “
O. insculpta, Hall	“ “
O. Daytonensis, Foerste	Clinton.
O. fausta, “	“

Platystrophia group. (Shell impunctate.)

P. biforata	Chazy—Clinton.
P. “ var. lynx, Eichwald	Hudson River—Cincinnati group.
P. “ “ acutilirata, Conrad	“ “
P. “ “ laticostata, James	“ “
P. “ “ crassa, “	“ “

O. plicatella group. (Shell impunctate.)

O. tritonia, Bill.	Chazy ?
O. Sweenyi, Winchell	Trenton.
O. pectinella, Conrad	“
O. plicatella, Hall	“ & Hudson River—Cincinnati group.
O. fissicosta, “	“ “
O. triplicatella, Meek	“ “
O. æquivalvis, Hall	“ “
O. Jamesi “	“ “
O. subquadrata, “	“ “
O. Kankakensis, McChesney	“ “
O. ? Whitfieldi, Winchell	“ “
O. flabellum, Sowerby	Niagara.

O. tricenaria group. (Shell impunctate.)

O. costalis, Hall	Chazy.
O. tricenaria, Conrad	Trenton—Hudson River.
O. disparilis, “	“
O. Halli, Safford	“
O. merope, Bill.	“ — “ “
O. Davidsoni, Vern.	Niagara.

O. testudinaria and O. elegantula group. (Shell punctate.)

O. perveta, Conrad	Chazy—Trenton.
O. subæquata, "	"
O. gibbosa, Bill.	"
O. Minneapolis, Winchell	"
O. testudinaria, Dalman	Trenton—Hudson River.
O. " var. multisecta, Meek	"
O. " " emacerata, Hall	"
O. " " Meeki, Miller	"
O.? clytie, Hall	Trenton.
O. elegantula, Dalman	Niagara.
O. planoconvexa, Hall	Lower Helderberg.
O. concinna, "	" "
O. perelegans, "	" "
O. subcarinata, "	" "
O. lenticularis, Vanuxem	Corniferous.
O. cyclas, Hall	Hamilton.

O. hybrida and O. Vanuxemi group [*Rhipidomys*, Œhlert]. (Shell punctate.)

O. hybrida, Sowerby	Niagara.
O. tubulostriata, Hall	Lower Helderberg.
O. oblata, "	" "
O. musculosa "	Oriskany.
O. Cumberlandia, "	"
O. Livia, Bill.	Corniferous.
O. Vanuxemi, Hall	" & Hamilton.
O. Missouriensis, Swallow	Chouteau.
O. Burlingtonensis, Hall	Burlington.
O. Swallovi, Hall	"
O. Thiemei, White	"
O. Michelini, L'Eveille	Knobstone.
O. Pecosi, Marcou	Upper Carboniferous.

O. resupinata and O. propinqua group [*Schizophoria*]. (Shell punctate).

O. circulus, Hall	Clinton.
O. multistriata, "	Lower Helderberg.
O. propinqua, "	Corniferous.
O. Iowensis, "	Hamilton.
O. Tulliensis, Vanuxem	Tully.
O. resupinoides, Cox	Upper Carboniferous.

Bilobites (*Dicoelosia*). (Shell punctate).

D. biloba, Linn.	Niagara.
D. varica, Conrad	Lower Helderberg.

ON NEW GENERA AND SPECIES OF THE FAMILY DICTYOSPONGIDÆ.

NEW FORMS OF DICTYOSPONGIDÆ FROM THE ROCKS OF THE CHEMUNG GROUP.

BY JAMES HALL.

[*Abstract.*]

Since the publication of the preliminary discussions of the genera and species of this remarkable group of organisms, much additional material of interest has come into my hands, largely from the rocks of the Chemung group in Alleghany and adjoining counties in New York. This formation has already furnished 14 species of the genus *Dictyophyton*, and besides, the curious basket sponge, *Uphantænia*, and probable though incomplete evidences of the genera *Phragmodictya* and *Ectenodictya*. It is now necessary to add two new genera to this number, *Actinodictya* and *Cryptodictya*. The group proposed for discussion in my final work on the reticulate sponges now includes 12 genera and sub-genera represented, *at present*, by 46 species. Of these—

2 are from the Utica slate.
1 is " " Hamilton shales.
24 are " " Chemung group.
7 " " " Waverly.
12 " " other horizons of the lower Carboniferous.

There are at least two other species remaining undescribed, and by the end of the present season I expect to record at least 50 species.

The new species and genera comprise the following :

Dictyophyton sceptrum, sp. n.
Formation and locality. Chemung group, Alleghany county, N. Y.

Dictyophyton vascellum, n. sp.
Formation and locality. Chemung group, Alleghany county, N. Y.

Dictyophyton Randalli, sp. n.
Formation and locality. Waverly group, Warren, Pa.

Dictyophyton scitum, sp. n.
Formation and locality. Chemung group, Chemung Narrows, N. Y.

Dictyophyton Amalthea, sp. n.
Formation and locality. Chemung group, Great Bend, Pa.

Dictyophyton ? (Phragmodictya) Halli, sp. n.
Formation and locality. Chemung group, Alleghany county, N. Y.

Dictyophyton tomaculum, sp. n.
Formation and locality. Chemung group, Alleghany county, N. Y.

ACTINODICTYA, gen. nov.
Actinodictya placenta, n. sp.
Formation and locality. Chemung group, Steuben county, N. Y.

CRYPTODICTYA, gen. nov.
Cryptodictya Alleni, sp. n.
Formation and localities. Chemung group, Steuben and Cattaraugus counties, N. Y.

Sir WILLIAM DAWSON remarked, concerning the subject of the latter paper: We in Canada, have now got as far back as the Siluro-Cambrian and Cambrian systems in the history of the Dictyospongidæ, several species of *Protospongia* and *Cyathospongia* having been obtained from the Quebec group. We have thus got a little further back in the series than you have in the United States. We have also another genus of the same group, which Hinde describes under the name of *Acanthodictya*. Twelve species in all are described in a paper on Fossil Sponges of the Quebec group, now in the press for the transactions of the Royal Society of Canada. Another point to which I would refer relates to the opinions entertained on the animal nature of these curious forms. Many years ago Professor Hall was kind enough to send me specimens of them. I had grave doubts about what they were, but could not refuse to call them plants, because there were no traces of spicules upon them, and there seemed to be evidences of an external membrane; and therefore I thought they could scarcely be sponges. They were then named *Dictyophyton*. A little later the intercrossing spicules were found, and I was shown a specimen of them in the Natural History Museum of New York; and I was then very thankful to be able to say I had been mistaken, and that we could no longer regard them as plants. We are, I think, very much indebted to the President for the work he has bestowed upon these interesting organisms, which constitute so marked an instance of a permanent animal type, culminating in a very early period.

The Society then took a recess until 2 p. m.

At the appointed hour the Society reassembled, Vice-President Alex. Winchell occupying the chair.

The following communication was presented:

THE STRENGTH OF THE EARTH'S CRUST.

BY G. K. GILBERT.

[*Abstract.*]

The term crust is here used to indicate the outside part of the earth, without reference to the question whether it differs in constitution from the interior.

Conceive a large tank of paraffine with level surface. If a hole be dug in this and the material piled in a heap at one side, the permanence of hole or heap will depend on its magnitude. Beyond a certain limit, further excavation and heaping will be completely compensated by the flow of the material. Substitute for paraffine the material of the earth's crust, and the same result will follow, but the limiting size of the hole or heap will be different, because the strength of the material is not the same. Assuming the earth to be homogeneous, the greatest possible stable prominence or depression is a measure of the strength of its material.

It is not believed that the earth is homogeneous, and with reference to the outer portion of the crust it is known that it is not composed of homogeneous shells. There is observational basis for the theory that the matter composing and lying beneath continents is lighter than the matter composing and lying beneath ocean beds, and many students of terrestrial physics entertain the theory that unit columns extending from the surface downward have everywhere the same weight, the height of each

column being inversely as its mean density. In accordance with this theory, prominences and depressions of the surface exist in virtue of a principle of equilibrium, called isostatic.* Under hydrostatic equilibrium the surface of a free liquid is level; under isostatic equilibrium the surface of a non-homogeneous solid, capable of viscous flow, is uneven.

There are thus two possible explanations of the inequalities of terrestrial surface, and these may be characterized severally by the terms rigidity and isostasy.

In connection with a study of Lake Bonneville, a large body of water temporarily filling a basin of Utah during Pleistocene time,† observational data were gathered bearing on the question of rigidity versus isostasy.

1. The Wasatch mountain range is carved from a large block of crustal material, uplifted along a fault plane at one side. The block adjoining the fault plane on the opposite side is thrown down. Erosion is continually transferring material from the uplifted block to the down-thrown block, and there is direct evidence that the mountain is steadily rising or the valley sinking, or both. Some advocates of the isostatic theory would regard this progressive relative displacement as a direct effect of the continual transfer of load. Under this view the mountain block has less density than the valley block, and the two are in isostatic equilibrium; the unloading of the mountain block by erosion and the loading of the valley block by deposition disturb the equilibrium, and it is restored by vertical movement on the fault plane.

An arm of Lake Bonneville occupied the valley, filling it to an average depth of 500 or 600 feet, and this load of water was somewhat quickly added and afterward somewhat quickly removed. If the valley block were delicately sensitive to the application of load, it should be depressed about 200 feet by the access of water, and should rise a corresponding amount when the water was removed. But this did not occur. On the contrary, the depression of the valley, as shown by changes occurring along the fault plane, continued alike during the presence of the water and after its removal. It is therefore concluded that the local transfer of load from one orogenic block to the other is not the primary cause of the progressive rise of the mountain and depression of the valley, and the question arises whether the mountain range may not be wholly sustained in virtue of rigidity.

2. Considering the main body of Lake Bonneville, it appears from a study of the shorelines that the removal of the water was accompanied, or accompanied and followed, by the uprising of the central part of the basin. The coincidence of the phenomena may have been fortuitous, or the unloading may have been the cause of the uprising. Postulating the casual relation, and assuming that isostatic equilibrium, disturbed by the removal of the water, was restored by viscous flow of crust matter, then it appears (from the observational data ‡) that the flow was not quantitatively sufficient to satisfy the stresses created by the unloading. A stress residuum was left to be taken up by rigidity, and the measure of this residuum is equivalent to the weight of from 400 to 600 cubic miles of rock.

From these phenomena and theoretic considerations arises the working hypothesis that the measure of the strength of the crust is a prominence or a concavity about 600 cubic miles in volume.

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* For definitions of the new term "isostasy" and its adjective "isostatic," see Dutton in Bull. Phil. Soc., Washington, XI, p. 53, and Woodward in Am. Jour. Sci., 3d Series, Vol. XXXVIII, 1889, p. 351.

† An account of Lake Bonneville may be found in the Second Annual Report of the U.S. Geological Survey, 1881, pp. 167–200.

‡ These data are not yet fully published, but will appear in a memoir on Lake Bonneville now in press, constituting Vol. I of the Monographs of the U. S. Geological Survey.

If this hypothesis is strictly true, then there should be no single mountain mass and no single valley, due purely to the local addition or subtraction of material, having a greater volume than 600 cubic miles. At least four kinds of mountains and valleys are due simply to the addition and subtraction of material: (1) mountains of extravasation (such as volcanic cones) beneath which the pre-existent terranes lie undisturbed; (2) mountains of circumdenudation, produced by the removal of surrounding material; (3) mountains produced by extravasation *and* circumdenudation; (4) valleys of erosion, unaccompanied by phenomena of displacement.

A large number of such mountains and valleys exist, and some of the largest occurring in the United States have been mapped in contours by the U. S. Geological Survey, so that their volumes can be computed readily.

San Francisco Mt., in Arizona, a result of extravasation, has a volume of 40 cubic miles.

Mt. Shasta, probably due to extravasation only, has a volume of 80 cubic miles.

The Tavaputs Plateau, or Roan Mt., lying on the borders of Utah and Colorado, and produced by circumdenudation, has a volume of 700 cubic miles.

Mt. Taylor, and the Taylor Plateau, in New Mexico, resulting from extravasation and circumdenudation, have jointly a volume of 190 cubic miles.

The Henry Mts., resulting from volcanic intrusion and circumdenudation, have a volume of 230 cubic miles.

The Sierra La Sal, a mountain group of the same type, has a volume of 250 cubic miles.

The deeper portion of the Grand Cañon of the Colorado, from the mouth of the Little Colorado to the mouth of Kanab Creek, is due to the removal of 350 cubic miles of rock.

The Tavaputs Plateau slightly exceeds the hypothetic limit; the other illustrations fall within it.

In view of the phenomena cited, and of the considerations and comparisons adduced, it is believed that the following theorem or working hypothesis is worthy of consideration and of comparison with additional facts: *Mountains, mountain ranges, and valleys of magnitude equivalent to mountains, exist generally in virtue of the rigidity of the earth's crust; continents, continental plateaus, and oceanic basins exist in virtue of isostatic equilibrium in a crust heterogeneous as to density.*

Professor A. Winchell: It strikes me that Mr. Gilbert's position is pretty nearly correct. I thought when he commenced that he was likely to discount the old doctrine of surface inequalities existing by virtue of rigidity in the crust. I found in the end, however, that he recognizes the validity of the old, generally received theory that the height of mountains depends upon the rigidity of the crust. He recognizes that, as I understand. I think that view, connected with the earlier suggestions of Sir John Herschel and some of the later determinations of his son, is one so well established that it would require very unquestionable facts in the line of those Mr. Gilbert has furnished to overthrow the conclusions in which geologists generally are resting. It is obvious, also, that there is truth in the suggestion that inequalities depend partly for their existence upon differences in the density of the material, and so far as Mr. Gilbert has used that principle in its application to the continental saliences of the earth's crust, I do not know but he is entirely within the limits of probability. Notwithstanding my adherence to the old doctrine, I am ready to admit there are certain

saliences which may depend on relative densities. If I have not caught correctly the speaker's views and discriminations he will of course put me right.

Professor CHAMBERLIN: I would like to inquire to what area Mr. Gilbert limits the four and six hundred cubic miles.

Mr. GILBERT: That raises a question I have not answered to my own satisfaction. It seems clear to me that the imposition of a long, narrow ridge will be no more effective in producing deformation than a small portion of the same ridge, but it is not clear whether a broad lens of added matter will be as effective as a more compact lens of the same weight.

Mr. HAY: There is a series of effects in connection with the outcrop of the lignite in the upper part of the Dakota formation in Kansas, which has suggested to me similar thoughts to those of Mr. Gilbert. In places the lignite is a usable variety of coal, used locally for fuel. It is worked almost entirely by drifts into the sides of the hills, and in no case have I known a shaft or well on the high prairie adjoining to strike lignite, and in the cases where the mines have had any extended working it always thins out as it enters the body of the hill. The lignite is the softest body of material in the ridges, and it seems as if the removal of the pressure by the cutting out of the valleys and plains has somewhat thickened it or pressed it out a little. I do not know a single instance in which it has been pierced by a deep well on the prairie.

Professor STEVENSON: I would like to say a word or two incidentally. With respect to the matter of shear, I think we have made a mistake in a great many cases. The theory has prevailed, and does prevail very extensively still, that ordinarily folding has advanced so slowly that, speaking in a general way, the particles of rocks adjusted themselves and crushing was avoided. Depending on that theory I was led into a grievous error, which might have led to the loss of several millions of dollars, and which did lead to a loss sufficiently great to bring discomfort. After examining the tunnel locations on the line of the South Pennsylvania Railway in Pennsylvania, I stated that in those passing through the Pocono sandstone, which is about 1,100 feet thick in that region, very massive and apparently very solid, arching would not be necessary. Accordingly contracts were let for a full double track railroad just there, and the tunnels were made the full width. A year later I was sent for in great haste by the President of the Construction Company to come out there and see what was the matter with these sandstone tunnels. Something was very wrong. The fact of the matter is that these sandstone tunnels needed to be arched more strongly than the tunnels in slate. In the folding the rock had been crushed into enormous wedges, which had slipped back and forth on each other, and naturally the adjustment was very bad. That was the only shear down there, and lines which were found all along the surface on the top, containing quartz, and which had been a puzzle to many persons, proved to be the planes between these several wedges; and the tunnel in Wray's hill, Bedford county, Pa., shows the condition only too well, for there one of these enormous wedges was a little narrower than the tunnel, and kept settling down until at last it became a cause of great anxiety. The same condition was found in the other mountain wherever we cut through this sandstone; the sandstone did not adjust itself a bit more than the Utica shales, which had been crushed into small fragments which were pressed on each other and rubbed back and forth until those shales where cut by the tunnels in Franklin county, Pa., are but a mass of lenticular pieces, some of them not much larger than a man's hand. So the question of shear, on which we have all depended, is not quite so clear in my mind as it used to be.

Dr. J. C. BRANNER: I would like to ask Mr. Gilbert whether he has considered this subject in connection with the subject of glaciation, and whether he believes the weight of ice has anything to do, or much to do, with the northward depression of this country during the glacial epoch.

Dr. A. C. LAWSON: I would like to ask Mr. Gilbert whether he included the greater inqualities or the less inequalities.

Mr. GILBERT: I will speak first in reference to the matter of shear, referred to by Professor Stevenson. The generalization, based on many observations, that the material of the earth's crust, under suitable conditions of pressure and confinement, yields to shearing stresses by flowing, finds its exception near the surface, for there the conditions of confinement do not compel flow, but permit fracture; and it may be added that the result is affected also by differences in the strength and texture of various rocks. But at a great depth, the rock subjected to shearing strain is held closely in its place and cannot part asunder, and the result is a diffused shear, or flow. I conceive that in a general way the phenomena of fracture are quite superficial, belonging to a tract extending five to ten miles downward from the surface, and that the phenomena affecting the larger problems of terrestrial physics are phenomena of viscous flow.

With reference to Dr. Lawson's question, which possibly I do not fully understand, I would say that I believe a broad observational basis underlies the general proposition that the ocean beds are heavier than the material of the continents. The data have been ably discussed by Pratt, Fisher, and Faye, and the mathematical researches of George Darwin appear to me to demonstrate, not, indeed, his conclusion that the earth is immensely rigid, but the fallacy of his postulate that the earth is homogeneous as to density. Moreover, as he himself points out, we have a very decided intimation, in the grouping or bunching of land masses on one side of the earth and of the ocean on the other, that the distribution of terrestrial densities is not symmetric. If it were symmetric, the center of mass would be the center of figure, and the oceanic waters would be drawn as much to one side as to the other.

Dr. Branner refers to the bending down of the earth's crust by the weight of the great ice sheet. I regard that hypothesis as most valuable, and one that will stimulate investigation. It is too early yet to accept it or reject it. I may say that it is my own working hypothesis, but I see the opportunity to gather an immense mass of material pertaining to the subject, and until that material has been gathered it will be unwise for us to tie ourselves to any one theory.

The substance of the next paper read is contained in the following abstract:

BOULDER BELTS DISTINGUISHED FROM BOULDER TRAINS—THEIR ORIGIN AND SIGNIFICANCE.

BY T. C. CHAMBERLIN.

[*Abstract.*]

For obvious reasons, boulders were among the first phenomena of the drift to attract attention, and occupied a large share of consideration in the earlier days of investigation of glacial phenomena. In recent years attention has been more largely directed

to other factors of the drift. But attention has turned again to a study of certain phases of the distribution of boulders. This has led to some distinctions and classifications that have bearings of importance upon the working out of glacial phenomena and the determination of the methods of glacial action. Two leading types need discrimination and distinct recognition: (1) boulder trains, and (2) boulder belts. Boulder trains take their origin from knobs or prominences of rock which lay in the path of glacial advance and gave off boulders readily and abundantly to the over-riding ice. Such trains lie in the line of glacial movement, but the boulders are not carried forward in strictly parallel lines. They may therefore appropriately be called boulder fans. The boulders are of a single kind, or at least of the few kinds represented by the parent knob. They usually grow smaller and more worn as traced away from it. They mingle with the underlying drift, and in this respect differ from the boulder belts presently to be considered. A part of the significance of these trains has been read, but much additional significance remains to be developed. Special investigations are in progress at the east by Professor Shaler, and at the west by Professor Buell and myself, the results of which cannot here be appropriately given.

The boulder belts differ from the boulder trains, in that they lie transverse to the direction of glacial movement. They are also contrasted with them in that the boulders, instead of being of one or a few kinds, are of many kinds, and, instead of being derived from some near source, came from distant sources. The boulder belts that have been especially studied by myself are found in Illinois, Indiana, and Ohio. The boulders of these belts were derived almost exclusively from the crystalline or Archæan rocks, 300 to 500 miles to the northward. There is an almost complete absence of boulders derived from the intermediate Paleozoic rocks, although such boulders occur in abundance in the moraines with which the boulder belts are associated and in the drift sheets and gravel hills with which they are connected. Another striking characteristic is the fact that the boulders are superficial, and do not mingle deeply with the underlying drift, as is the case in the boulder fans.

In distribution, the boulder belts have been found to coincide closely or nearly with terminal moraines, a fact which strongly suggests that they were deposited by the margin of the ice that formed the moraines. The solution of the problem presented by these boulder belts may be found in an analysis of terminal moraines. A glacier deposits material at its margin in three ways: (1) It pushes matter forward mechanically, ridging it at its edge, forming what may be termed push moraines. (2) A glacier may fail to carry forward to its actual extremity the material which it is pushing at its base, and this may lodge under the margin, forming a submarginal accumulation which may be called a lodge moraine. (3) A glacier carries forward the material embraced within the ice or borne on its top until it reaches the extreme margin, when it is dropped, forming what may be called a dump moraine.

These boulder belts are held to belong to the last class. It is believed that boulders were dislodged from the high hills of the Archæan highlands at some distance up in the ice as it passed over them, and that these were borne onward in the ice at some distance above its base until they reached the margin, where they were necessarily dropped on the surface. If this be true, it follows as an important inference that the basal portion of the ice did not rise toward the surface, for in that case the abundant local drift would have been mingled with the foreign drift, which is conspicuously not the fact. This stands opposed to the doctrine advocated by some that, owing to "frontal resistance," the basal currents rise, carrying boulders up to heights above their source.

Professor A. WINCHELL: Some of the phenomena to which President Chamberlin alludes are well known within those regions that have become familiar to my own observation, and particularly within the lower peninsula of Michigan. I have attempted to explain the absence of fragments of Corniferous and Niagara limestones between their northern out-crops and the southern boulder areas by the fact that they are of a calcareous character. We have, for instance, about five hundred definable species and varieties of Archæan boulders, and these boulders have been transported from the regions about Lake Superior, let us say, to the north, and to the south probably. But we have very few boulders derived from the limestones which out-crop in the vicinity of Mackinaw and Drummond Island, and the reason seems to me obvious. The limestones resist the destruction which has been incident to the movement of these boulders far less completely than the Archæan fragments do; the limestones have been worn out or dissolved, and have disappeared; but the Archæan 'boulders have endured the transportation, and hence they are with us. I should think perhaps a consideration of such facts should enter into President Chamberlin's conclusion in reference to currents of boulders that originated from remote points, and those others from the immediate vicinity in which the boulders are discovered. It might be said that there are indeed trains of calcareous fragments, large and small, but particularly small, of a local character that have been derived from the formations over which the glacier has passed within a distance of five or ten miles; but speaking of boulders of remote transportation, the limestone boulders are few and the Archæan boulders are many.

Professor G. F. WRIGHT: This paper is of special interest to me because it brings to view familiar phenomena in portions of the country which I have not visited. My own observations have been, to a very considerable extent, on the extreme margin of the glaciated area, and certain phenomena which occur there seem to be analogous, if not altogether identical, with those described by President Chamberlin. What Professor Lewis and myself denominated the "fringe" seems to correspond very closely to these bands of boulders in front of the larger deposits. For a time this "fringe" was neglected by us, but as our examination progressed we came to see that there was never, or at least very rarely, a piling up of material at the very margin, but that the piling up occurred somewhat back of the extreme margin. We concluded, both from the nature of the case and from the facts under observation, that the rapidity of motion in the ice, which is well known to be greatest near the middle portion of the current, continually decreased up to the very margin, where of course there was a complete cessation. This would result in what we uniformly found, namely, that there were very generally boulders thrown over to a considerable distance beyond other marks of direct glacial action. The appearance was as if they had been carried over on something corresponding to breakers upon the seashore successively advancing on each other. Probably the advance of the ice-front was interrupted by periods of rest, allowing moraine material to accumulate at various stages of its progress. With every further advance the ice would rise and flow over this moraine and rework the material and drag it along underneath. Finally, at the extreme margin, we have this fringe of boulders from which the ice retreated permanently. If there were periods of cessation in the retreat, wherever a line of equilibrium was established this accumulation of moraine material, with a fringe in front of it, would take place in reverse order and be left for permanent inspection. Thus the bands of boulders of which President Chamberlin has given such an interesting account would seem to be a series of fringes to what I should call the "moraines of retrocession."

My observations upon the Muir glacier, in Alaska, confirm this view of the case. Where the ice projects upon the mainland there is no precipitous wall as where it debouches into the water of the inlet, but the ice gradually diminishes in amount and forms an inclined plane; and for a mile or more the debris borne upon the surface of the glacier is carried over the incline of the ice-front and deposited upon it to such a depth as almost wholly to conceal it. Here is an instance of the way such accumulations take place in an actually retreating ice-front. Were the ice to re-advance, instead of pushing this material along in front, the upper strata would move over it.

The phenomena connected with the lifting of boulders in the ice should be considered in this same connection. In our report upon the glacial boundary in Pennsylvania, mention is made of large numbers of boulders on the top of Kittatinny mountain which must have been brought from ledges whose out-crop is several hundred feet lower. From the direction of the striæ, Professor Lewis supposed they must have come from Godfrey's Ridge, which is a thousand feet lower than the summit of Kittatinny mountain, and not more than twelve or fifteen miles distant. Professor Lesley says that the rock of which these boulders consist is nowhere found in place less than 500 feet below their present situation.

I have noticed also the absence of sandstone, shale, and limestone boulders from the marginal belt, but accounted for it by the same considerations which Professor Winchell has presented, namely, a survival of the fittest. The Archæan rocks are better fitted to survive the transportation than rocks of a softer nature and than those which are more susceptible to dissolving agencies.

Professor C. H. Hitchcock: It is quite exhilarating to an eastern man to hear about the transportation of these boulders so many miles. It is with great difficulty we can find anything that has gone more than forty or fifty miles, so the question can be studied to better advantage in the west than in the east. There is one point I wish to ask Professor Chamberlin about. I understood him to refer to the transportation of material in the upper part of the ice as different from that lower down. I desire to know if it is a common thing to make out that the upper part of a glacier is transporting material in an altogether different direction from that in the lower. In reference to boulder fans, I think the term is a very happy expression; it reminds me somewhat of a similar dispersion we have in the east, and I thought it possible that the scattering of the fragments could be explained by the transportation of the upper part differently from the lower.

The example is what I have described in the New Hampshire report, the boulders starting from Mt. Ascutney, in Windsor, Vermont, an isolated peak about 3,000 feet above its base on Connecticut river. Its material is a peculiar granite not easily confounded with any other rock. The disposal of the boulder has been recognized on radial lines having an angle of fifty degrees with each other, and the greatest distance of transportation is fifty miles.*

President Chamberlin: The observation of Professor Wright regarding the transportation of boulders from a lower to a higher elevation does not seem to me to appeal to anything but the ordinary laws of flowage. Boulders within a current of ice are like particles of silt suspended in a current of water; they are merely material carried in suspension. The material rises and falls according to the inequalities of the bottom if it is pushed on or carried near the bottom, and if it is carried near the surface it follows the general decline of the surface. Now, silt going over the weir

* Geology of New Hampshire, part iii, 1878, p. [illegible]. It would be possible to conceive of the stones carried southeasterly as transported [illegible] the course of the ice movement, and of those found in the direction of S. 6° W. as having been transported by the local Connecticut glacier.

of a dam may lodge on its crest. So, boulders going over a mountain range may lodge there, having been carried up by the natural laws of basal flowage. This basal flowage does not affect the general course pursued by the current. It is a very different proposition from the general doctrine of a rise of current.

In respect to the fringe, I cannot take the time to say what I would be glad to say on the subject; but I regard the fringe in western Pennsylvania as the edge of an old drift, which has there just escaped burying. Traced further west, we find an attenuated drift border for hundreds of miles; we have similar phenomena in the carrying of boulders far out beyond any considerable mass of drift, in some instances very many miles. I may state that along this border from Ohio westward to the Rocky Mountains, we have practically nothing on the edge of the drift that I should denominate a terminal moraine. We have, of course, a termination of the drift; but no accumulation such as we have been accustomed to designate a terminal moraine. In the latitude of Bismarck boulders reach westward of any definite terminal moraine to the extent of forty miles, and in the latitude of Pierre there is an exceedingly attenuated distribution of boulders, stretching out a dozen miles or more beyond the thicker distribution on the east side of the river. In the immediate vicinity of the Rocky Mountains, after striking the first boulders from the northeast, I had to travel two hours before finding any others or any signs of northeastern drift. So this phenomenon of attenuated distribution of boulders has a very wide range, and cannot be accounted for, I think, by anything in the line of the suggestions of this paper or of Professor Wright, unless we fall back upon the general proposition that these boulders were transported in the ice, and borne out beyond the point where the ice had the power to push along its subjacent debris. I do not look upon the fringe as being in a proper sense a fringe. I look upon what was called a fringe in western Pennsylvania as the attenuated edge of a drift formation.

In regard to the transportation of boulders within the ice in different directions from those transported on the face of the ice, I have no considerable mass of data that would answer that question in the affirmative.. In the region I have studied the transportation of materials has in general been in practically parallel lines; I have not been able to determine that the englacial currents of the ice were in any essential sense different from those on the surface. I think in general they moved in a common direction. If there were cross-currents, I think they were quite subordinate in the interior region.

The following paper was then read by Mr. C. D. Walcott:

STUDY OF A LINE OF DISPLACEMENT IN THE GRAND CAÑON OF THE COLORADO, ARIZONA.

The paper will be found appended, printed in full.

The communication represented by the following abstract was then presented:

ON THE TRAP DIKES NEAR KENNEBUNKPORT, MAINE.

BY J. F. KEMP.

[*Abstract.*]

The paper opened with a brief reference to the geological reports which touch this region (those of Maine and New Hampshire), and showed that the published material

was meager. The general geology was then outlined. The rocks are metamorphic quartzites, slates, and schistose strata, standing vertically and penetrated with bosses of granite and dikes of trap. A map drawn to scale illustrated their distribution. Mention was also made of the neighboring rocky promontory of Bald Cliff, and this was likewise illustrated by a map. The microscopical characters of the massive rocks were next described at length. The granite was first taken up and shown to be a normal granite in the bosses, while in the dikes it approximates a granite-porphyry with a very coarsely crystalline ground-mass and very large phenocrysts. The occurrence of vein-fillings on the borders of the granite, consisting of quartz, feldspar, tourmaline, and muscovite was cited as evidence of fumarole action.

The dikes were next treated, some seventy-five or more different ones having been studied. They were shown to be holocrystalline and porphyritic examples of the olivine-diabase series, although some departed more or less from the type. Their mineralogical composition was discussed at length, the most interesting features being the occurrence of brown basaltic hornblende in one or two, and the approximation of the dikes to typical camptonites. Some discussion of this latter group followed. Attention was also given to the structure of the dikes in broad and narrow examples, and on edges and in center. While, in general, in the narrow dikes and on the edges a porphyritic facies is to be seen, and in the centers an approximation to granular structure, nevertheless, some of the broadest examples are porphyritic all across and some of the narrower ones more granular; also some of the very narrow dikes are quite holocrystalline, with relatively large phenocrysts of olivine. Three principal types were made out in all: the olivine-diabase, the augite-porphyrite, and the melaphyre, with hornblendic and more rarely biotitic departures from the same. One or two analyses were appended; and the paper closed with a brief discussion of the related dike rocks hitherto described in this country, and they were shown to be principally of diabase affinities. A tabulation of the Kennebunkport dikes by numbers which referred to the map, with their widths and petrographical determinations, concluded the contribution.

In the absence of the author, the Secretary then read the following paper:

THE SYLVANIA SAND IN CUYAHOGA COUNTY, OHIO.

BY PETER NEFF.

Unquestionably the Sylvania sand is found in the well drilled by the Cleveland Rolling Mill Co., at their works in Newburg, near Cleveland, Cuyahoga county, Ohio. This sand is quartzose, bright and sharp, a good glass sand. Its position' is in the Niagara series and its presence here, however anomalous, is unmistakable. It lies about 1660 feet below the mouth of the well, and is about forty feet in thickness. I quote from Professor Edward Orton, State Geologist, Geological Survey of Ohio, Vol. vi, 1888, page 352:

"The well-head is about seventy-five feet below the bottom of the Berea grit, and about 780 feet above tide." Limestone was reached at 1350 feet; sand at 1660 feet to 1700 feet. Professor Orton says of the latter: "It is a sharply crystalline, unworn sand, of which many of the grains are unusually perfect. It matches well in position to the Sylvania sand of Lucas county. This, it will be borne in mind, is no longer to be referred to the Oriskany horizon, but it is buried under 150 or 200 feet of

the Lower Helderberg limestone. If this Cleveland sand is not the equivalent of the Sylvania sand, it is obviously a similar deposit."

This Rolling Mill well reaches the Clinton red limestone, at about 3050 feet, being fully 1000 feet above the Trenton limestone. This well demonstrates the existence of vast rock salt deposits, which show an original depression in the surface here at that age.

There is a well bored on the Jewett farm about one and one-quarter miles south of the Cleveland Rolling Mill well. It is on ground fully one hundred feet above the mouth of the Cleveland Rolling Mill well. This well is located above the Berea Grit, southeastwardly from the quarry, near the Insane Asylum. At 1414 feet it was through the Erie and Huron shales and struck limestone. The limestones and shales below this are similar to those in the Cleveland Rolling Mill well. At 1720 feet salt water was struck; at 1780 feet, or two or three feet in the Sylvania sand, a supply of gas was found, and the well was drilled no deeper. This was in July, 1888. Allowing for difference in elevation between this well and the Cleveland Rolling Mill well, the sand is found at about same depth. This well has not been drilled through the sand. It is cased, but makes about eight gallons of salt water per day. It yields, I should judge, about 150,000 to 175,000 cubic feet of gas per day, and has continued to do so excepting when the salt water has been allowed to accumulate. The gas has the general characteristics of the Findley gas, with perhaps not quite so much sulphureted hydrogen in it. I did not see the pressure gauged, but was told at the well that on one occasion it was, in half an hour, 225 pounds and rising. The same parties bored another well on the Jewett farm, locating it about 500 feet south of the other and on about five feet higher ground. Its drillings are the same as the other two wells previously referred to; but this well was bored through the Sylvania sand, which was about thirty feet in thickness and drilled about 50 feet below the sand, in all about 1860 feet. In the sand in this well but very little gas was found. From 1720 feet, veins of salt water were met. This well was not successfully cased, and on reaming it for re-casing, in July, 1889, the tools became fastened in the well.

Still another well has been put down during the past year, which gives some additional interest to the Sylvania sand. It is located in Euclid township, near what is known as "The Old Salt Works," on the Smith farm, and is about half a mile from the shore of Lake Erie. It is about thirteen miles northeast from the Cleveland Rolling Mill well, and not far from the town of Nottingham, in Cuyahoga county, Ohio. The mouth of this well is from 60 to 70 feet above the level of Lake Erie. It struck limestone at 1168 feet, salt water at about 1470 feet, and found the Sylvania sand at 1540 feet, with no gas; found this sand rock 50 to 75 feet thick, and very sharp and fine grained sand. Well not cased and abandoned at 1685 feet deep.

Here, then, we have four deep wells, whose geological developments are similar and conformable one to the other. The measurements are as accurate as I could obtain from the parties in charge of the wells. These four wells do not encourage deep boring in the hope of striking, in Cuyahoga county, a pinnacle of the Clinton limestone which is found petroliferous in some parts of the State of Ohio, and much less in the hope of finding the Trenton limestone in condition for either gas or oil.

The Jewett farm well, which is producing the gas from the Sylvania sand, indicates, however, a new horizon in which gas and perhaps oil may be stored. By reason of some natural connection with the petroliferous formations in the Clinton

and Trenton series, it may prove the receiver or store house of large, continuous supplies. It is a horizon of fine grained sand, which will slowly give out its accumulations, so that its wells will be of moderate capacity but long-lived. A series of such moderate sized wells will probably produce a supply of considerable value. There is certainly no use here in drilling entirely through the Sylvania sand. Salt water is found both above and below the sand.

How far this Sylvania sand extends is not developed. It has not, I believe, been encountered in any of the deep wells south of Cuyahoga county. That its general trend is northeast at an angle of about 46 degrees, will, I think, be demonstrated by the drill. Previous to the Carboniferous age there was unquestionably a dividing ridge, or slight anticlinal, through this part of what is now Cuyahoga county, which in a measure divided the great ocean of the lake region from the Appalachian sea. Conformable with this ridge or elevation, the Sub-Carboniferous formations were more or less affected, giving rise to the present position and elevations of the Sub-Carboniferous series; notably of the Berea Grit, which may be taken as the index stratum of this great series. Now, starting at the Cuyahoga river and going northeastwardly, this Berea Grit rises above the level of Lake Erie to about 350 feet in Euclid township, where the tops of the hills are higher, and on Euclid creek there are fine exposures; and in the same general course northeastwardly toward Painesville this zig-zag ridge or water-shed continues. There are well-marked places indicating that this ridge was a shore line. The Berea Grit, a hard sand, is found tapering out to a feather edge, and can be traced on its dip south to a thickness of thirty feet in a few miles, and is not cut off by glacial action. Again, many of the gullies three to four hundred feet deep on the general strike of the out-crop of the Berea Grit, strongly indicate that this rock or shore line formed a barrier to the ice sheet, and the cut took place northeast to southwest along the edge of this shore line, giving the present configuration to these deep gullies.

I argue from what I have thus briefly given, that there is an elevation so covered as to give the features and peculiarities of the present surface, and that this ridge has on it the continuation of the Sylvania sand. How far north and south, or to what extent toward the northeast it continues can only be determined by boring. But that it is here, and that it lies under Euclid township at such an elevation and position as to make it a store-house for gas and oil, I have no doubt. A few wells judiciously put down would triangulate this section and determine the interesting question whether this sand is in position and a store-house for holding the gas and oil rising from the underlying 2,200 feet of limestones and shales. If so, this sand would bear some coincident similarity to the horizon of the Berea Grit as to its location and use in being superincumbent to gas and oil producing formations; for the Berea Grit lies above the Huron Shales, and through the interlying 550 feet of Erie Shales gas and oil pass to it as a store-house.

The Secretary then read two papers, in the absence of the author, under the following titles:

THE HIGH CONTINENTAL ELEVATION PRECEDING THE PLEISTOCENE PERIOD.

BY J. W. SPENCER.

ANCIENT SHORES, BOULDER PAVEMENTS, AND HIGH-LEVEL GRAVEL DEPOSITS IN THE REGION OF THE GREAT LAKES.

BY J. W. SPENCER.

These papers will be found appended to the Proceedings of this meeting.

After some remarks from Vice-President Winchell, the Society adjourned to meet in the American Museum of Natural History, New York city, on December 26, 1889, at 10 a. m.

AREAS OF CONTINENTAL PROGRESS IN NORTH AMERICA, AND THE INFLUENCE OF THE CONDITIONS OF THESE AREAS ON THE WORK CARRIED FORWARD WITHIN THEM.

BY PROFESSOR JAMES D. DANA.

It has long been recognized that the continent of North America has its nucleal area of Archæan rocks; that the nucleal V has the same courses in its general outline as the continent; and that there are ranges of Archæan ridges, more or less interruped, approximately parallel to the outline of the V; among them, one along the Appalachian chain, and another along much of the Rocky Mountain chain. Further, the positions of the ranges of the Appalachians and the Rocky Mountains were, in 1875, made by me the basis of a division of the continental surface into (1) an Eastern Border region, east and northeast of the Green Mountain range; (2) an Appalachian region, along the Appalachians west of the Archæan ranges from Alabama to Canada, the Green Mountain area included; (3) an Interior Continental basin, between the Appalachian chain and the Rocky Mountain chain; and (4) a Western or Pacific Border region, "west of the Rocky Mountain Summit," as the four great partially distinct areas of continental progress.

My subject at this time is: The areas of continental progress in the light of existing facts, and the influence of their conditions on the work carried forward within them.

1. In the first place I observe that the boundaries separating the Atlantic and Pacific borders from the Continental interior should be drawn, as far as possible, along the ranges of Archæan ridges just referred to. These were boundaries at the beginning of Paleozoic time; and they have been ever since the more important division-lines for noting progress. On account of the Archæan origin of these axial lines in the two mountain chains, and the fact that in their elevation the existence of the Appalachian and Rocky Mountain chains had their beginning, I propose to call each the Archæan protaxis of the chain. The Appalachian protaxis extends along the Green Mountain region as an interrupted range, and is continued through Putnam and Orange Counties, New York, northern New Jersey, eastern Pennsylvania, and thence southwestward to Georgia, as a series of ridges, and in some parts nearly parallel ridges, making part of the wide area of crystalline rocks.

The protaxis is not now the highest part of the chain, but it is the oldest part; and although an embryonic feature in the continent, it probably had once great height throughout, which it has lost by time's long erodings.

Much the larger part of later fragmental rocks, limestones excepted, are made out of what the Archæan ridges have lost.

2. Again, the Archæan ranges east of the Appalachian protaxis and those west of that of the Rocky Mountain are entitled to like recognition in the continental history.

To the northeastward, over the New England and Canada extension of the continent, there are two or more such ranges.

First. An Archæan range of prominent importance crosses—with some interruptions and approximately parallel ridges as usual—New Brunswick from the south side of Chaleur Bay, on the Gulf of St. Lawrence, having outliers in southwestern New Brunswick, passes southwestward to the coast-region of Maine east of Mt. Desert, and thence continues as a broad belt into Eastern Massachusetts and perhaps into Eastern Connecticut. It is a boundary between two Paleozoic regions. On its eastern side it has fossiliferous Cambrain and later Paleozoic rocks in New Brunswick and Eastern Maine, Upper Silurian occurring in Machias, Pembroke, and elsewhere, and fossiliferous Cambrian in Eastern Massachusetts—all belonging to the western border of the eastern of the two Paleozoic regions; and on its western and northwestern side there is the large Paleozoic basin of Middle and Northern Maine. And if we follow the western outline of this Archæan range from Maine into Massachusetts, we find that the Nashua synclinal of argillite and mica-schist, just west, is probably an extension of the Maine Paleozoic to Worcester, where anthracite, graphite, and carboniferous plants occur as evidence of the existence of the coal formation. The lines on Prof. Edward Hitchcock's Geological Map of Massachusetts, in his quarto report of 1841, correspond well with this view, and the descriptions of the rocks by Mr. L. S. Burbank and Prof. W. O. Crosby favor it.*

Secondly. A second range of probably Archæan rocks commences in the northern part of western Newfoundland and is continued southwestward, with the usual interruptions, along Nova Scotia. This second Archæan range and the preceding are the confines of the great trough—Bay of Fundy trough it might be called—in which lie the Carboniferous and other Paleozoic rocks of New Brunswick, Nova Scotia, and western Newfoundland, and the Triassic rocks of the borders of the Bay of Fundy, of undetermined

* Mr. L. S. Burbank in Prof. W. O. Crosby's "Report on the Geological Map of Massachusetts," 1876, in which Mr. Burbank's observations are published as a separate paper; also Professor Crosby in his Geology of Eastern Massachusetts, Boston Soc. N. H., 1880.

Professor Hitchcock's Map, in his Report of 1841, represents the synclinal of mica-schist as having along the center a broad belt of clay slate, and he describes the slate (pages 127, 556, and also page 55 of his Report of 1835) as becoming a fine-grained imperfect mica-schist at Worcester, where it contains a bed of anthracite a few feet thick. The mica-schist is described as arenaceous and in some places passing into quartz rock. Amos Eaton, in his Geological Text-book (1832), speaks of the rock at Worcester as argillite containing "anthracite and impressions of ferns." In Harvard, to the east of north of Worcester, the area of mica-schist contains a ridge of granite, and east of this ridge, according to Mr. Burbank, a coarse conglomerate occurs, which to the south blends with the conformable mica-schist. The area of argillite and mica schist widens northward and bends northeastward into the Merrimac valley at Lowell. On the east of the synclinal lies the Archæan area.

thickness, as well as the Triassic of Prince Edward Island. To this trough the coal formation of Rhode Island and an adjoining part of Massachusetts with its associated Cambrian may belong—as long since suggested; for the soundings strongly favor the idea that this Nova Scotia range extends on beneath the ocean's border, and, as recognized by Prof. W. O. Crosby in his Geology of Eastern Massachusetts, that it has its continuation, under ground, in the Cape Cod and Plymouth region of southeastern Massachusetts.

Other approximately parallel Archæan ranges may exist farther eastward in Newfoundland as boundaries of Paleozoic troughs; but the published facts do not enable us now to define them.

Thirdly. A third range of probable Archæan extends along New Hampshire, on the east side of the Connecticut valley, through Massachusetts into Connecticut, dividing the Paleozoic trough of Maine from that of the Connecticut valley; and this Connecticut valley trough ended its rock-making career, like that of the Bay of Fundy, in the laying down of some thousands of feet of Triassic beds.

Through these Archæan ranges we thus have the confines of three troughs: The Connecticut valley trough; that of Maine and western New Brunswick, extending southward to or beyond Worcester, Mass.; and the Bay of Fundy trough, covering eastern New Brunswick and western Nova Scotia and Newfoundland, with much of St. Lawreuce Bay, and extending probably far to the southwestward in or beyond the coal region of eastern Massachusetts and Rhode Istaud. All three opened northward into the great St. Lawrence Gulf which in early geological time occupied the region of the St. Lawrence river valley.

It is not to be inferred that such troughs were alike from north to south in rock-making. The Connecticut valley trough had thick deposits of Upper Silurian and Devonian rocks laid down in its northern half, which implies deep subsidence, and at present we have no evidence that similar depositions took place in the southern half. It had its thick deposits of Triassic beds in the southern half, which we are quite sure did not extend through the northern half. But, notwithstanding such independent work in the different parts, it was one trough in its Archæan confines, and in its relations to the general system of progress.

It thus appears that Archæan operations first established the boundaries, and that Paleozoic and Mesozoic rock-making went on in the troughs between these boundary ranges; and, further, in view of the great thickness of the rocks, that all the troughs were profoundly, and more or less independently, subsiding areas.

There is this limitation to the conclusion, that "Paleozoic rock-making went forward within the troughs." The earlier part of this Paleozoic rock-making, that of the Cambrian and Lower Silurian, went on not only in the

troughs, but overstepped their boundaries. This overstepping was true even for the Appalachian region, and, consequently, rock-making areas of subsidence were not then so narrowly limited in Eastern North America as they were afterward. These early Paleozoic formations, the Cambrian and Lower Silurian, spread from the interior continental seas across the lower parts of the Archæan protaxis, filling the seas between the Archæan islands and extending to the Atlantic border south of New York, and probably to the Connecticut valley on the north.

But after the Lower Silurian era had passed, and also the epoch of disturbance closing the era, this overstepping the boundaries of the troughs in Eastern North America was, in general, no longer a fact. The Upper Silurian, Devonian, and Carboniferous rocks never extended over the Green Mountains or beyond the Taconic range, for the region—that is, the Green Mountain area—had, in the mean time, emerged. Moreover, it is not yet known that these strata spread eastward from the Interior Continental area over any part of the crystalline rocks of the Atlantic Border region, or, I might say, over any part of the Atlantic Border region. They may and probably do exist on the border beneath the Cretaceous and Tertiary, or beneath the ocean's margin; but they are not yet known from actual observation to have extended east of the Archæan protaxis. The Jura-Trias of the Atlantic border rests in many places on Archæan, Cambrian, or Lower Silurian, but not as far as yet known on later Paleozoic rocks. According to Prof. G. H. Cook, of New Jersey, borings through the Cretaceous formation between New York and Trenton, N. J., reach only crystalline rocks, much resembling those of New York island.

The boundary-range separating the Interior Continental region from the Atlantic Border region was, hence, greatly widened before the Upper Silurian began, by the addition to the Archæan of the Cambrian and Lower Silurian formations, and their addition to a considerable extent in a crystalline or metamorphic state. They were added in the metamorphic state in western New England, where we have Lower Silurian and Cambrian strata in a crystalline condition combined with the ranges of Archæan—those of the protaxis—and all together in combination making up the Green Mountain area as it existed in the period of the Upper Silurian. There is no question as regards the Taconic system here involved. For the discoveries of fossils by the Vermont survey, and by Wing, Walcott, and Dwight, have definitely proved that the Archæan is bordered and combined in the Green Mountain region with Cambrian and Lower Silurian strata; and, being thus combined, it was emerged before the Upper Silurian era began. The Archæan protaxis of the Appalachian region was similarly combined with Lower Silurian; for uncrystallized Cambrian and Lower Silurian strata are visibly so associated, and besides this, it is probable that part of the crystalline

schists are Lower Silurian, as has been suggested by several writers on the region.

Moreover, the protaxial area, thus widened, was probably, throughout later Paleozoic time, an emerged area to the south as well as to the north—that is, it was above the level of marine waters. Great subsidence took place over the Triassic areas of the Atlantic Border region—2,000 to 5,000 feet at least—but it took place without letting in salt water. They were local subsiding areas or troughs.

The same widening of Archæan boundary-ranges by an inclusion of Cambrian and Lower Silurian areas probably took place, also, in New Brunswick and Nova Scotia.

Fourthly. These facts from Eastern America with regard to the break between the Lower and Upper Silurian make it apparent, and more so than has been hitherto recognized, that the close of the Lower Silurian era marks off one of the grander divisions in American geological time, as it does also, though less strikingly, in that of Europe. The importance of the epoch in geological history is manifest also in Western America; for while evidence of any disturbance fails, the Upper Silurian is to a large extent absent or nearly so, if we may judge from known facts. Consequently, the boundary lines of the Lower Silurian areas, not unfrequently omitted, are among the most important of the lines which a geological map of North America, or of the world, should contain.

I take this opportunity to add, as a second corollary, that there is good reason in the importance of the Lower Silurian era—good chronological, geological, and paleontological reason—why the name Silurian, which the Lower Silurian has so long held, should be perpetuated to it, and good reason why the name should not become attached only to the small end of the Silurian era, the so-called Upper Silurian, which has little in its new types that is not more characteristically Devonian, and which has not one-fourth the area of distribution or thickness of strata in North America that the Lower Silurian has. There is reason for this also in what is due to the name of Murchison, whose labors for his "Siluria" where largely among the Lower Silurian rocks, and whose troubles with Sedgwick came out of their separate labors in Lower Silurian and Cambrian rocks without the intention in either of encroaching on the other's rights.

The Upper Silurian may conveniently take a new name, but it is not necessary to go for it to the same little land of Wales that has supplied the two, Cambrian and Silurian, in honor of Sedgwick and Murchison. We may better look elsewhere for the third name. There is the land of Bohemia, where Barrande worked out his Silurian and Primordial systems, and there is the area of New York and Canada where were laid the foundations of American Paleozoic geology, and where our honored president, James Hall, has carried on his paleontological labors.

The term Bohemian has been already used for the Upper Silurian by the French geologist, M. de Lapparent, in his Treatise of 1883. The name Ontarian is suggested by the actual use of the term "Ontario Division" for the lower portion of the Upper Silurian by Mather, in his New York Geological Report of 1843, and by Emmons, in his Report of 1846. And it is in its favor that Upper Silurian rocks prevail over much of Ontario, Canada.

Cambrian, Silurian, Ontarian, would make a satisfactory triplet. Whatever name shall be adopted for the Upper Silurian, the working ground of Barrande, or that of Hall, Billings, and others should some way be recognized, and to this even the distinguished author of the term Ordovician would not, I am sure, enter his dissent.

Fifthly. I come now to the "Interior Continental" region. Three subdivisions are suggested by the geology and ancient topography of the region, which have eminent importance as regards rock-making. The mountain-making disturbance which followed the close of the Lower Silurian left, as Newberry has shown for Ohio and Western Indiana and Safford for Tennessee, a region of shallow seas and low emergences along a belt extending southwestward, parallel nearly with the Appalachian protaxial area, from the west end of Lake Erie to Southern Tennessee—a region which has been long called the "Cincinnati uplift." The Canadian geologists find the influence of the uplift extending farther north, to Lake Huron. The course of this region of shallow seas and emerged land may be made the first division line through the Interior Continental sea.

The second I would draw along the western limit of the Paleozoic areas on the geological map of the country, or, what is the same thing, along the eastern limit of the Mesozoic, from Western Iowa southward to Texas and northwestward to the Arctic coast. The Paleozoic area on the east of the line was at the time, for the most part, the non-subsiding land of the continent. The Mesozoic area on the west of the line was the immense subsiding area, for the area had the length of the continent from south to north or rather northwest, and it continued its sinking through the Triassic, Jurassic, and Cretaceous periods, or at least, if ceasing for part of the Triassic and Jurassic, it went on through part or all of the Cretaceous period. What determined this strong boundary line or limit is not clear; possibly some underground Archæan feature. And perhaps uplifts at the close of Paleozoic time help to mark it, if Prof. Robert T. Hill is right in referring the steep upturning and flexing of the Carboniferous rocks of Western Arkansas and the adjoining Indian Territory to the close of the Permian period.

These two boundary lines divide the Interior Continental region into three great sections: (1) The Eastern Interior east of the Cincinnati uplift; (2) the Central Interior or Mississippi Basin; and (3) the Western Interior or that of the Eastern Rocky Mountain slope. Of the four subdivisions laid

down by me in 1875, the Appalachian area corresponds to the Eastern Interior. Prof. H. S. Williams, in his communication on the Devonian in 1887 to the committee of the International Geological Congress, recognized the fact that the term Appalachian and my definition of it gave it too narrow limits and used that of Eastern Interior.

The Central Interior might be further divided into an East-Central and West-Central, along a line commencing in the chief Archæan region of Missouri, an island, or group of islands, in the Paleozoic sea, to the west of which the Upper Silurian and Devonian strata appear for a long, undetermined distance to be mostly or wholly wanting.

The title of my paper includes, as its second clause, "the influence of the conditions of these areas on the work carried on within them." I will now illustrate this point by going into some detail with regard to one of these sections, the Eastern Interior.

The influence of the Cincinnati barrier on subsequent rock-making has been recognized by Professor Hall, Professor Newberry, and others, but I think that this influence was much greater than has been appreciated. Note the position and length of this partial barrier of shallow seas and emerged lands between the Western and Central Interior, its extension from Lake Erie, or the southeast side of Lake Huron to Southern Tennessee and somewhat beyond it, and then consider the size of the area enclosed, namely, parts of Mississippi, Alabama, and Eastern Tennessee, Eastern Kentucky, West Virginia, Eastern Ohio, nearly all of Pennsylvania, and all of New York, except its northern portion, the length not less than 700 miles. Note also that the great subsiding Appalachian trough, or group of troughs, extended over a broad eastern portion of the area, and that the subsidence involved to some extent the whole.

Now, when the Upper Silurian era opened, the region of Albany in Eastern New York was near the head of a great Northeast Bay in this Eastern Interior Sea. It was essentially a bay; for the old sea-channel of the Lower Silurian era, extending over the Lake Champlain region to Canada, in which the Lower Silurian formations had in succession been laid down, was closed by the beginning of the Upper Silurian, as the records of the Niagara period show, or, at least, so far closed as to be no longer a contributor toward rock-making, and it continued to be thus far closed except during the Lower Helderberg period, through the rest of Paleozoic time.*

* The closing of the channel need not have been so complete through all this time as to have excluded the intermigration of species. But it is probable that the chief open passage eastward between the Atlantic and the Continental Interior was over Eastern Pennsylvania where the Archæan protaxis has now for a long distance its minimum height. The waters over this wide connecting region have left no evidence of their presence in rock formations of the Upper Silurian, Devonian, or Carboniferous eras east of the protaxis, but this they would not be likely to do unless the region were a region of slow subsidence, since any beds laid down would have been very thin and easily washed away.

This Northeast Bay must have received the embryo Hudson, a stream then of little length but of abundant Adirondack waters; and also such other streams as the slopes and rains could produce; but no salt-water currents nor tides bearing sand and gravel from Canada and the Atlantic borders on the northeast. And even in the Lower Helderberg period, when it is supposed (first by Logan) that the broad Champlain Lake region was again under salt-water, there were no contributions of coarse sediment from the Canada and Labrador region, although there must have been of living species, for the Lower Helderberg rocks over the region are limestones, and mostly argillaceous limestones. An opportunity for such fragmental contributions by these Champlain Straits may have existed in the epoch of the Cauda Galli grit, at the commencement of the Devonian, as suggested by the presence of its beds, according to Prof. Wm. M. Davis, over the lower Helderberg in Becraft's Mountain, east of the Hudson river; but this is not probable.

I would add that the closing of the Lake Champlain area against the sea cotemporaneously with the emergence of the Green Mountains, and its continuing to be essentially closed, signifies that the region of the Appalachian subsidence no longer embraced the Green Mountain and Lake Champlain area, although it continued to extend over much of the eastern half of New York, as we learn from the many thousand of feet in thickness of the later Upper Silurian and Devonian formations.

Observe here what a blow the fact of this closed Northeast Bay gives the old theory—which I have held as well as others—that the coarse and fine sediment for Appalachian rock-making, during the Upper Silurian era and afterwards, came in, period after period, from the northeast, through Labrador currents. The facts from the distribution of New York and Canadian Devonian and Carboniferous rocks bring us to the unavoidable conclusion that all the sedimentary beds of New York and the Alleganies, through the Upper Silurian, Devonian, and Carboniferous eras, though so many thousands of feet thick, were made within the Interior sea out of material derived, so far as non-calcareous, from the wear of rocks about it, and that the tidal and other currents of the Interior sea distributed the material.

This Eastern Interior sea, while closed in the direction of Albany, had, during the Niagara period of the Upper Silurian, a wide open way westward over Ontario, Michigan, and Northern Ohio; and here the tides entered as freely as from the southwest. But afterwards, in the Salina and Lower Helderberg periods, it became much less free, though still open, for the Cincinnati barrier made transitions in these Interior regions easy from an open clear sea to great areas of salt-pans over west-central New York, and still wider regions of salt-water and brackish-water flats, such as the depositions of the Salina and the Water-lime beds prove to have existed. The salt

pan region referred to was nearly 200 miles in length from east to west, and that of the shallow sea-flats of the Water-lime over three times this length.

The western passage way, or that over Michigan and Northern Ohio, was again deep and widely open through most of the Corniferous period. Afterward there was again a narrowing and a shallowing. It is easy, with the geological reports of the State of New York and those of the other States along the Eastern Interior region, to follow out the various changes that came over the area and its western open way, and also the coming on of the area of alternating emergences and submergences characterizing the coal period. I have been over the records, but have to confine myself here to a few prominent points,

The conditions of such a bay during the Upper Silurian, Devonian, and Carboniferous eras would have influenced tides, currents, temperature and purity of waters, sediments, life, and everything that could have affected rock-making and biological distribution. The conditions were varied, also, by oscillations in the water-level, and here and there by the throwing up of long beach-made or sand-flat barriers. In either way, great shallow confined seas, like Pamlico Sound and others of the Atlantic border, but perhaps larger, might at times have existed, especially as the waters became more shallow; and such seas would have been likely to vary from purely marine to intensely briny, on one side, and to brackish and fresh on the other.

These few particulars are enough to make it manifest that the consequences of the geographical conditions in the Eastern Interior sea must have been of most comprehensive range.

As regards life, the head of the Eastern Interior region, comprising the area of New York and Pennsylvania, would have been the least favorable of the whole Interior Continental sea for pure-water species. Whenever depth and purity of water favored, such species would have gone in and flourished and made limestone, as they did during much of the Niagara and Corniferous periods. But, in general, pure-water species would have been, and were, absent. The species outside would have migrated in or not according to their habits, and readily, for where there are tides and currents migration of marine species is rapid work. But under such circumstances the stratigraphical succession could not correspond to the true biological succession of species. It would be only local-condition succession. Prof. Henry S. Williams established this conclusion fully by the facts from the Devonian of New York which he presented to the American Association in his very valuable paper of 1885,* and Prof. C. L. Herrick has recently drawn attention to similar facts and presented explanations of similar import.† They

* H. S. Williams, on the classification of the Upper Devonian, Proceedings of the Amer. Assoc., 1885, p. 222; also geographical and physical conditions on modifying fossil faunas, ibid, 1884, p. 422.

† C. L. Herrick, Geology of Licking Co., Ohio, Bulletin of Denison University, Vol. IV, p. 97, in a paper continued from Vols. II and III. Mr. Herrick's conclusions are stated in a series of "geological aphorisms," on pages 98 and 99, and all of them enforce the principle above stated.

may well lead geologists all over the world to consider the question: How large a part of the stratigraphic succession of life, which is made so much of by the careful noting of zones, is only local-condition succession? Walcott's discovery, in the Eureka Devonian beds, that many species of the New York, Hamilton, and a few Chemung species occur in the Lower Devonian of Eureka and some Lower Devonian of New York in the Upper of Eureka* give emphasis to the reasons for careful and comprehensive study before conclusions as to biological succession are endorsed "established."

I might illustrate also the influence of the varying conditions, in such a Northeast Bay, on rock-making, but add only a single thought. In the matter of the tides, how exceedingly varied are the circumstances that would have attended deposition in consequence of the changing positions and force of the tidal currents which variations in depth and other causes would have occasioned! Conglomerates would have been formed where the currents were strongest. But, in the same long geological epoch, the strongest tidal current out of the great Northeast Bay might have had many different positions over western New York or Pennsylvania or over eastern Ohio, and thus conglomerates would have been made at various levels, which the geologist might, unless cautious, take as equivalents.

The Central Interior and Western Interior regions I pass without special remark, although they derive great interest from study parallel with that of the Eastern Interior.

The Pacific Border region owes its maximum width, which occurs in the United States portion, to the east and west bend of the Archæan protaxis of the Rocky Mountains in Wyoming and Southern Montana. This Archæan bend carries eastward, in a somewhat irregular way and more than 250 miles, the part of the protaxis south of the bend.

Over the Pacific border, there are, as has been recognized, two prominent lines or series of mountain ranges nearly parallel with the coast: (1) The Coast chain, which includes the Coast ranges south of Vancouver's Island, and the island ranges along the coast northward; (2) The Cascade chain, as it may be called, including the Sierra Nevada, the Cascade range of Oregon and Washington Territory, and ranges of mountains in British America that are nearly in the same line. Neither chain has a well-defined Archæan axis except for a small part of its course, and this is probably owing to the

* C. D. Walcott, Paleontology of the Eureka District, 298 pp., 4to., with 24 plates of fossils, 1884, U. S. Geological Survey. The lower part of the Eureka Devonian limestone contains many Upper Heiderberg species of New York and other States east of the Rocky Mountains. But with these are many that are Middle and Upper Devonian in New York and elsewhere; among these, the three Hamilton Tentaculites, *T. attenuatus*, *T. bellulus*, and *T. gracilistriatus*. Besides this, some New York Upper Helderberg species are found in the upper part of the 6000 feet of Devonian limestone, as *Cladopora prolifica* Hall, *Chonetes mucronata* Hall, *Euomphalus laxus* Hall (Upper Helderberg and Hamilton in New York). Again, many of the species of the lower part occur also in the upper, showing long survival of individual forms—*e. g.*, *Streptorhynchus chemungensis*, 4 species of *Productus*, *Chonetes deflecta*, *Strophodonta perplana*, 2 species of *Spirifera*, a *Paracyclas*, *Styliola fissurella*, *Rhynchonella castanea* Meek (a Mackenzie river species). Many of the species are represented in the Devonian of Iowa, or the Continental Interior, where the waters were purer and probably deeper than in the New York Bay, and therefore more like those of the Eureka District.

thickness of the later sedimentary formations and the igneous outflows. The Cascade chain, however, has an axis of granitoid and other crystalline rocks for the most of the Sierra Nevada portion, which is probably Archæan in time of origin; and the Archæan range is a long one, if it extends, as is reasonably urged by Mr. W. Lindgren, through the length of Lower California.

The intervening depressions, in the Pacific Border region, are first, the GREAT VALLEY region, between the Coast and the Cascade chains, comprising the valleys of the Joaquim and Sacramento in California, the Willamette in Oregon, and valley-like depression between the so-called Coast Ranges of British America; secondly, the GREAT BASIN region, whose eastern boundary is the Archæan protaxis in British Columbia, but in the United States, south of Montana, is a north and south line through the Great Salt Lake, as shown by King; thirdly, owing to the bend of the Archæan protaxis, widening so greatly the Pacific Border region, the United States, south of Montana, has a Rocky-Summit region, which is the third in the series of regions counting from the coast, while Washington and British Columbia have but two.

The eastern limit of the Great Basin region, distinguished by King, dividing it from the Rocky Summit region, is very nearly coincident with a southward extension of the northern part of the Archæan protaxis, or that north of the bend; and probably a series of Archæan ridges once continued along this line, of which we have remains in the outcrops in and near Salt Lake, including the high Archæan range along the Wahsatch Mountains, and in other ridges farther south. Whether a continuous range ever existed as a western boundary or not, the "Rocky Summit" region appears to be confined to the United States, and to have well-defined limits—the western line extending by Salt Lake west of south to the crossing of the parallel of 37° and the meridian of 115° W., and then bending southeastward to the borders of Texas and Mexico. West of the line for a long distance over the Great-Basin as King's Report shows, the Carboniferous rocks are the latest; directly east of it at many points begin the Cretaceous; and thus the distribution of the green areas of Cretaceous on a map makes it generally easy to trace the boundary, in spite of the great loss from erosion.

But so far as the northern boundary is concerned the "well defined limits" made by the Archæan have, geologically, only a superficial value. The region is actually continued, stratigraphically and orographically, into the high Rocky Mountain summit-belt of British America, although this belt is wholly east of the Archæan protaxis.

The identity between the two regions, one north and the other south of the Archæan bend, is apparent in several of their characteristics. Both are regions of Paleozoic and Mesozoic rocks, in which the Cambrian, Carbonif-

erous and Cretaceous formations (the Laramie included) make the chief part. Both are regions of great mountain-making displacements of post-Cretaceous occurrence. Both are the courses of high and bold mountains dependent for their origin on these displacements.

But there is a contrast in the extent and results of the displacements. South of the Archæan bend, the mountain-system is in part that well called the Plateau system by Major Powell; north of the bend, in British America, it is the Appalachian system, according to the results of the geologists of the Canadian survey, Dr. G. M. Dawson, and more definitely Mr. R. G. McConnell. Mr. McConnell, in his report of 1886 on the region about the pass through "the Rocky Mountains" of the Canadian Pacific Railway, describes and figures ordinary and overthrust flexures, and upthrust faults of 1,000 to 15,000 feet, precisely, says Mr. McConnell, like those "in the Appalachian region of East Tennessee, described by Prof. Safford"; and in one section, which he figures, there is a vertical displacement of 15,000 feet, and also a shoving of Carboniferous limestone almost horizontally over Cretaceous beds to the eastward for "a distance of nearly two miles." From the observations, the whole amount of horizontal displacement in this fault was estimated by Mr. McConnell to be seven miles. The resemblance to the Appalachian system includes the fact that the upthrusts and overthrusts were, in each observed case, landward in direction. Dr. Dawson's facts from the region south, nearer the 49th parellel, published also in the Canadian Geological Report for 1886, are similar as to the character of the flexures and faults except that some of the faults appear to be upthrusts westward. Mr. J. B. Tyrrell has obtained supplementary facts from northern Alberta. Further, the report of Mr. O. H. St. John, in the Hayden volume for 1877, contains a plate of sections across the Wyoming mountains in western Wyoming, south of the Archæan bend, representing flexures and faults like those described by Mr. McConnell.

I have not, myself, studied the region with reference to the transitions; but in view of the facts that the mountain-making to the north and south involved the same rocks to the top of the Laramie, and that these rocks were involved, therefore, in the same great subsidence attending the thickening of the accumulation of the Mesozoic beds as well as those beneath, I think we can hardly doubt that all is one in general system, orographically not less than stratigraphically, although successive portions of the summit belt may have had a degree of independence in the movements.

We learn from the facts, as we have also from those of Lower Silurian history, that an Archæan protaxis is not necessarily a fast boundary with regard to geological work. The Cretaceous seas spread among the Archæan heights, and in the region south of Montana for a long distance beyond them,

and, nevertheless, the orographic movements affected more or less the whole belt.

The later areas of rock-making, those of the Eocene Tertiary, which also were areas of profound subsidence, were bounded by the mountains which had just before been made and put into combination with the Archæan ranges.

As to rock-making within the Great Valley and the Great Basin regions, and the relations of the various local subsiding troughs in the latter, more facts are needed for any general conclusions.

From this review of the system of progress in a case of continent-making we learn that the areas of rock-making were defined for the most part in Archæan time; that their confines were old Archæan ranges, or else later uplifts made in accordance with the Archæan system; that on the Atlantic border the Cambrian and Lower Silurian formations were united to the Archæan so as to widen the Archæan or protaxial boundary range; and we have reason to conclude also that areas were rock-making so far and so long as they were subsiding troughs.

It is also seen that the larger part of the work of marine waters was done within interior continental seas without contributions of rock-material from outside or aid from the ocean's waves or currents, either those of the Atlantic or Pacific. For the most part, therefore, the growth of the continent, so far as through marine waters, may be said to have been *endogenous*. It began to be *exogenous* on the Atlantic side in the Cretaceous era, these beds there, and the Tertiary also, being of sea-border origin; yet vastly the larger part of the Cretaceous rocks of the continent, although marine, were made in interior seas.

Even the far east Paleozoic and Mesozoic area, including much of Nova Scotia and Eastern New Brunswick, had its outside Archæan boundary, and was a trough of Archæan confines, not the margin of the open sea. The open sea is a harsh region for rock-making, and only limestone-making through coral growths and the associated life appears to succeed well in the face of the heavy breakers.

It is of the highest interest to find, in such a review of events marking off the growth of the continent, that the grander lineaments were well defined, and the grander movements initiated, in its early beginning. Surely, there can be no mistake in the conclusion that the continent has ever been a unit in its system and laws of development; or the wider conclusion that all the continents "have had their laws of growth involving consequent features, as much as organic structures." *

* The Author's Expl. Exped. 4to. Report, p. 436, 1849.

STUDY OF A LINE OF DISPLACEMENT IN THE GRAND CAÑON OF THE COLORADO, IN NORTHERN ARIZONA.

BY CHARLES D. WALCOTT, OF THE U. S. GEOLOGICAL SURVEY.

Read before the Society, August 29, 1889.

CONTENTS.

INTRODUCTION.

During the summer and fall of 1882 I was engaged in studying the Paleozoic rocks of southern Utah and northern Arizona, north of the Grand Cañon of the Colorado river, and in the winter of 1882–'83 in a detailed study of the geology of a portion of the Grand Cañon. The area under investigation in the Cañon included its head, at the foot of Marble cañon, and the Grand Cañon with its lateral cañon valleys on the west, from Nun-ko-weap valley outlet to the westward turn of the cañon, where it cuts through the Kaibab plateau and exposes the Archean rocks in the depths of the inner cañon. A partial account of the notable sections of Algonkian and Paleozoic strata has been published,* but nothing has yet appeared relating to a line of displacement whose early history was mainly determined by the study of the stratigraphy within the cañon. To-day I wish to describe this displacement and also to call your attention to certain conclusions drawn from the consideration of the phenomena presented by it.

* Am. Jour. Sci., 3d ser., vol. 26, 1883, pp. 437, 442, 484. Bull. U. S. Geol. Survey, No. 30, 1886, Introduction.

The displacement has long been known as the East Kaibab fold of Powell.* Captain Dutton describes it as the longest line of displacement known to him: "Its total length, reckoning as one displacement the Wasatch, Grass Valley, Table Cliff, and Eastern Kaibab portions, cannot fall much short of 300 miles, and may considerably exceed that after the termini have been discovered. It presents many phases or modifications, but the dominant feature is the monoclinal form. The maximum displacement is at the Wasatch Plateau, and reaches nearly 7,000 feet."† The Eastern Kaibab portion of this great displacement will be considered apart from the more northern divisions. It extends as a monoclinal fold, with the down curve to the east, from the foot of the Vermilion cliffs in southern Utah, along the eastern side of the Kaibab plateau to the precipitous northern walls of Nun-ko-weap valley, in the Grand Cañon. Here the fold abruptly changes to a fault that extends to the southeastern walls of the cañon, where it again merges into the fold and disappears.

Butte Fault was the name which I selected and applied in my field notes on account of its connection with the origin and development of the six great buttes in the northeastern portion of the Grand Cañon. These buttes rise from 2,000 to 3,000 feet above the Colorado river and extend along its western side, from the narrow cañon outlet of Nun-ko-weap valley to the foot of Chuar valley, a few miles south of the mouth of the Little Colorado river. Not only the buttes, but the cañon valleys of Nun-ko-weap, Kwagunt and Chuar, and the visible line of the fault, are situated entirely within the great ampitheatre enclosed by the cañon walls to the southwest and west of the head of the Grand Cañon.

In order to clearly indicate the stratigraphic position and thickness of the strata affected by the east Kaibab fold and the Butte fault, the following table is inserted:

			Feet.
Tertiary			815
Cretaceous			3,095
Jurassic (identified)			960
Jura-Trias			3,430
Carboniferous	Permian	854	4,106
	Upper Aubrey Limestone	805	
	Lower " Sandstone	1,485	
	Red Wall Limestone	962	
Devonian	Temple Butte Limestone		94
Cambrian	Tonto (calcareous and arenaceous shales)		1,050
	" (sandstone)		
Algonkian	Chuar (shales and limestones)	5,120	12,950
	Grand Cañon (sandstones, with lava flows in upper part)	6,830	
	Vishnu (bedded quartzite and schists)	1,000+	
			26,500

* Expl. Colorado River of the West, 1875, p. 186. † Rep. Geol. High Plateaus of Utah, 1880, p. 33.

Description of the Butte Fault.—On the north, near the foot of the high walls in the lower end of Nun-ko-weap valley,* a hill formed of several flows of greenstone, contemporaneous with the deposition of the sandstone interbedded with the flows, is capped by a rough, massive, magnesian limestone (fig. 1). The pre-Cambrian Chuar strata dip away from it on the north and west, and an east and west section shows that the hill is a mass of strata displaced, in relation to the beds on the west of it, nearly 2,500 feet, the fault-line *c* (also *c* of figure 2) separating them sloping to the west with the down-throw. The eastern side of the hill is cut by two faults, *a* and *b* of fig. 1. The western fault *c* is sub-parallel to *b*, and brings to view the strata that underlie the lava beds of the main portion of the hill. The eastern (Tertiary) fault *a* has dropped the Chuar and Grand Cañon rocks on the east out of sight and brought the Cambrian Tonto sandstone down so as to form the eastern base of the hill. The sandstone beds are vertical, owing to the drag on the eastern side of the fault.

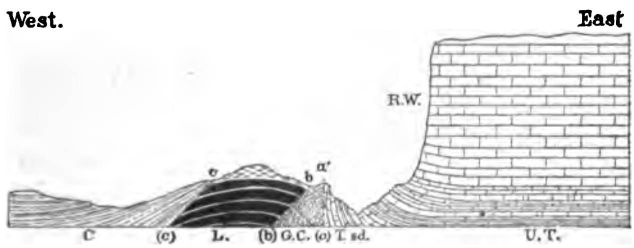


FIGURE 1.—*East and West Section at the lower end of Nun-ko-weap Valley on the North side of the Brook.*

R. W. = Red Wall limestone (Carboniferous); U. T. = Upper Tonto (Upper Cambrian); T. Sd. = Tonto sandstones (Middle Cambrian ?); C=Shales of the Chuar group (Algonkian); G. C. = Shaly sandstones of the Grand Cañon group (Algonkian) that belong below the lava beds L; *a*, *á* = Butte fault; *b*, *b* and *c*, *c* = Pre-Cambrian faults. Vertical scale, 1000 feet = 1 inch.

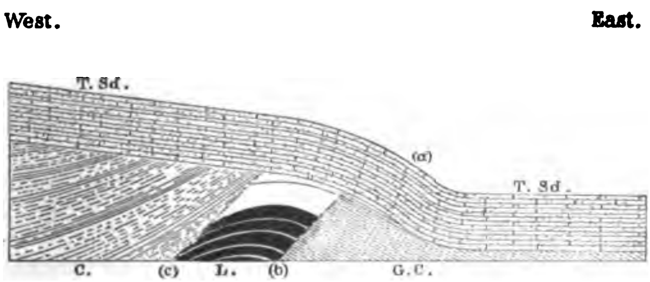


FIGURE 2.—*Section on the North side of Nun-ko-weap Valley.*

The lettering is the same as in fig. 1. The faults *c* and *b* are here seen only at the surface, but their connection with *c* and *b* of section 1 can be readily traced. The 700 feet of the Tonto group above the sandstone and the Carboniferous Red Wall and Aubrey groups are not represented in the drawn section, although occurring above the Tonto sandstone where the section was taken.

* Nun-ko-weap valley heads as a cañon on the east face of the Kaibab plateau, then widens out to a mile in breadth before contracting to its cañon outlet leading into the channel of the Colorado river. Its entire length is three miles. See maps accompanying Dutton's Tertiary History of the Grand Cañon, 1882.

In section 2 (fig. 2), which was taken 500 yards north of section 1 (fig. 1), at the north wall of the valley, the Cambrian Tonto sandstone and the superjacent Cambrian limestone arch over the line of the Butte fault with-

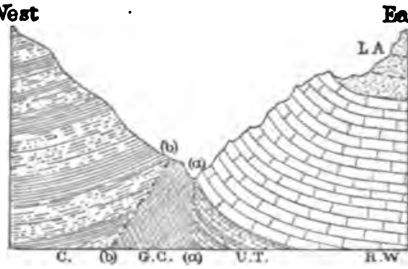


FIGURE 3.—*An East and West Section on the South side of the Nun ko weap Brook.*

The section faces north at a point opposite section 1 and south of the outcrop of lava besides the brook. L.A. = Lower Aubrey sandstone. Other letters and scale as in section 1.

out breaking, and the fault is limited to the pre-Cambrian movement that displaced the Chuar and Grand Cañon terranes of the Algonkian. The latter movement is shown by the faults *b* and *c*, fig. 2. Whether a pre-Cambrian fault existed on the line of the fault *a*, fig. 1, is unknown, as the debris covers the slope at the corresponding point in fig. 2.

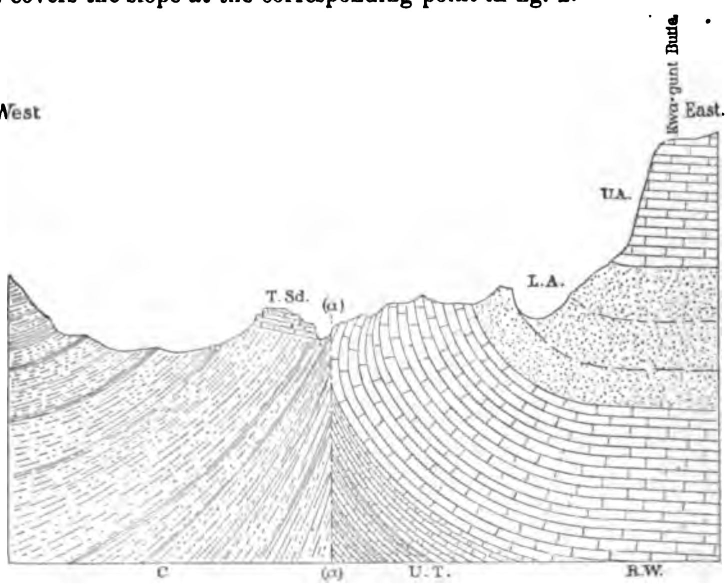


FIGURE 4.—*East and West Section on the East end of the Divide between Nun-ko-weap and Kwa-gunt Valleys.*

The rise on the west is towards Nun-ko-weap butte. U. A. = Upper Aubrey limestone; L. A. = Lower Aubrey sandstone; R. W. = Red Wall limestone; U. T. = Upper Tonto shaly limestone; T. Sh. = Massive Tonto sandstone; C = Chuar group shales; *a*, *a* = Butte fault. Scale as in fig. 1.

The throw of the Tertiary fault (a, a'), in section 1, is about 500 feet, and in section 3, taken one mile south, over 1,000 feet. One of the pre-Cambrian faults (section 3) has here disappeared; the other, probably b, or it may be b and c of section 1 united, has displaced a fragment of the Grand Cañon group more than 3,000 feet in relation to the Chuar group (see fig. 3).

In the next cross-section (fig. 4), taken on the divide between Nun-ko-weap and Kwa-gunt valleys, all the faults of sections 1, 2 and 3 are united, the pre-Cambrian and Tertiary movement having taken place on the same line of displacement. The upturning of the strata towards the fault is greatly increased, even to the reversing of the dip of the massive Red Wall limestone to 30° W.; and the throw of the fault to the eastward by the Tertiary movement is doubled. Owing to the upward curvature of the strata in the immediate vicinity of the fault, the displacement on the line of fault is not more than 500 feet; but measured a short distance back, where the actual displacement is shown by the position of the horizontal beds, the throw is from 2,000 to 2,200 feet. To this must be added the curvature of the monoclinal fold that occurred prior to the actual faulting. This, on the line of Kwa-gunt and Chuar valleys, varies from 500 to 700 feet, giving a total displacement between the strata on the east side of the Colorado river and on the summit of the Kaibab Plateau, of fully 2,700 feet, on a line crossing the strike of the East Kaibab displacement. This condition of the

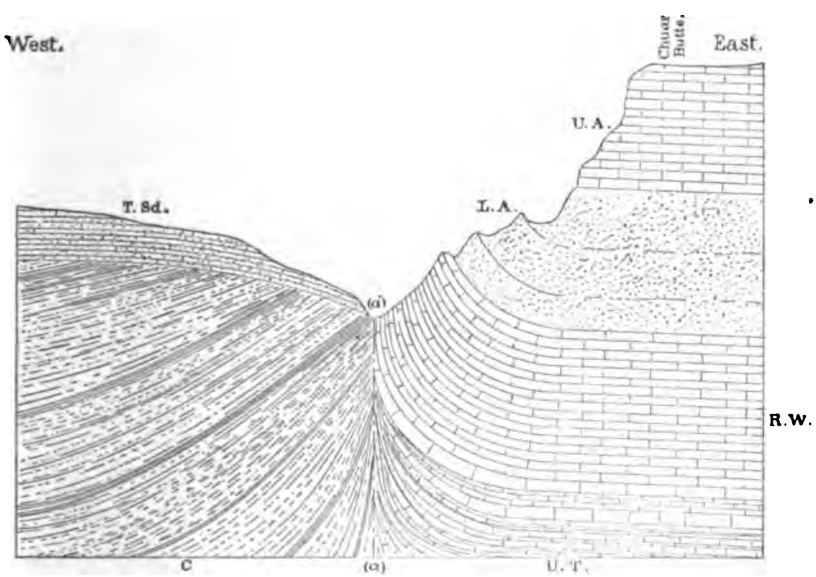


FIGURE 5.—*Section on the Divide South of the Kwa-gunt Valley.*

The section includes the west side of the Butte and also a portion of the divide on the ridge on the north side of Chuar valley. The lettering and scale are the same as in section 4.

fault continues several miles, the strata on the thrown side sometimes approaching the fault almost horizontally, but usually bending somewhat abruptly upward. They often stand vertically, and are so metamorphosed, flattened out, or compressed, that little of the original appearance of the rock remains.

Figure 5 represents a cross-section of the ridge south of Kwa-gunt valley, and figure 6 is a cross-section of the divide leading into Chuar valley on the north. The massive Tonto (Cambrian) sandstone curves gently down towards the fault, while the unconformable Chuar (Algonkian) beds beneath

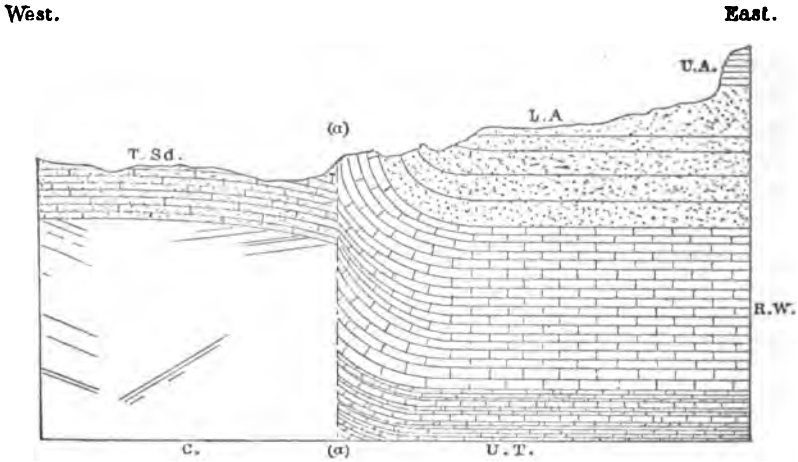


FIGURE 6.—*Section on the Divide North of the Chuar Valley.*

This section is of the same type as section 5. The lettering and scale are as in section 4.

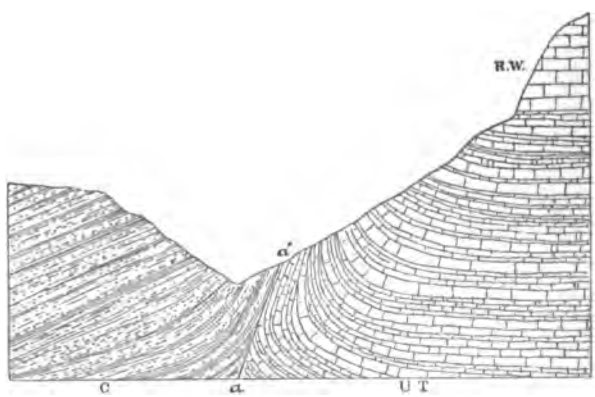
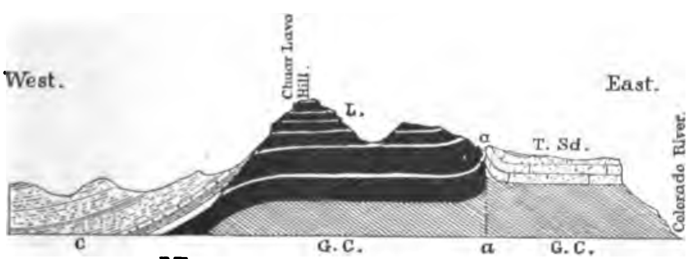


FIGURE 7.—*East and West Section at the entrance of the canon outlet of Kwa-gunt Valley.*

The Chuar shales (C) and the shaly Tonto limestones (U. T) are vertical or inclined a little to the west for some distance. The layers gradually curve back each way from the fault *a*, *a*, as shown in the section. Vertical scale, 200 feet = 1 inch.

and the strata on the east of the fault are flexed up on each side towards it; the Chuar strata were turned up in the downward throw, to the west, in pre-Cambrian times, and the Tonto, Red Wall and Aubrey rocks by the eastern throw in the movement producing the East Kaibab displacement. In several localities this has resulted in bringing the soft calcareous and argillaceous shales of the Chuar and Tonto groups side by side (fig. 7), and, as both are nearly vertical, no line of demarkation is observable although in the interval between the deposition of the argillaceous shales of the Chuar group and the bringing of the shaly calciferous beds of the Tonto into their present relations to them, upwards of 16,000 feet of sediments were deposited in the Colorado basin, and the geologic history of the greater portion of the North American continent was written.

The general direction of the fault has thus far been to the south-southeast. Midway between the Kwa-gunt and Chuar valleys it curves more to the southeast and then to the south, scarcely deviating from a north and south line until it reaches Chuar laya hill, where it forks. The east branch passes north of the hill. It crosses the Colorado river in a southeasterly course and runs out a short distance up a side cañon. Here the upper Tonto and Red Wall terranes arch over it in an unbroken monoclinal fold although, but a short distance away to the northwest, the massive Tonto sandstone is displaced by a downthrow of 400 feet to the northeast. The west branch of the fault continues south a mile or more and then bends to the southeast, crosses the river and disappears beneath the Tonto terrane, displacing the Grand Cañon and Chuar groups, but scarcely breaking the Tonto beds. The Tertiary movement appears to have followed the east branch; this is shown by a cross-section of Chuar lava hill that cuts across the two branches



P.T.

FIGURE 8.—*E. N. E. and W. S. W. Section through Chuar Lava Hill.*

T. Sd.=Lower massive Tonto sandstone; C.=Chuar shales; G. C.=Grand Canon shaly sandstones. The dip of the latter is the same as that of the lava beds (L) and the Tonto sandstone. *a*, *a*=East branch of fault; P. T.=West branch, and pre-Tonto fault. The western fault cuts through the lava bed and separates the western portion which is part of the highest lava bed brought down by the westward throw of the fault. The fault at this point is not shown in the figure.

of the fault (see fig. 8). One mile south of this section, on the west branch, the Tonto sandstone is not displaced by the fault, although the pre-Tonto throw, to the west of the strata of the Grand Cañon group, is from

1,200 to 1,500 feet. Upon this data the restored outline of the pre-Tonto position of the strata, prior to the Tertiary displacement at the crossing of section 8, is given in section 9. The west branch of the fault is inclined 30°

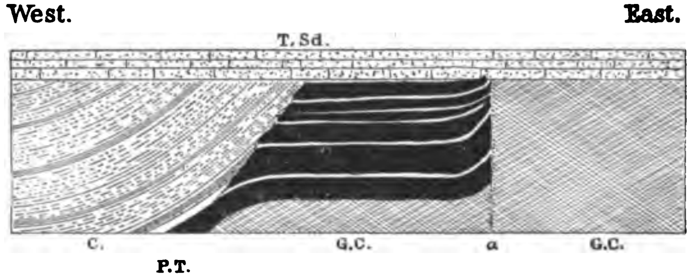


FIGURE 9.—*A Restoration of Section 8.*

Representing the block forming Chuar lava hill before the Tertiary faulting and erosion of Chuar valley and the Grand Cañon. The lettering is the same as in section 8.

from the vertical to the west, and the east branch is nearly vertical; a fact that serves to explain the Tertiary movement following the latter, as it was mainly a vertical displacement.

The pre-Cambrian Movement.—The westward throw of the pre-Cambrian (Algonkian) fault, varied at different points from 400 to 4,000 feet, owing to its traversing strata that dip both with and against its strike. All along its line, except in Nun-ko-weap and Chuar valleys and across the Colorado opposite Chuar valley, the strata on the eastern side are now concealed by the carrying down of the Tonto and superjacent rocks by the Tertiary movement. In sections 1, 2, 8, and 9 the pre-Tonto strata are shown on each side of the fault, and on the east side of Chuar valley the beds of the Chuar group are seen lying up against the west side of the lava hills, on the line of the oblique western branch of the fault (fig. 8). To the south the fault passes through a saddle eroded through the Tonto sandstone between the hill south of Chuar lava hill and the main ridge. This proves that the fault crossing the saddle, with a throw of from 1,200 to 1,500 feet, is of pre-Cambrian age, as the line of the Tonto sandstone has been scarcely more than broken by the slight reverse movement that occurred during Tertiary time on the main fault and its eastern branch. In every instance where strata of the Chuar group approach the fault the beds are flexed up towards it on a grand scale, as shown in sections 4, 5, 6, 7, and 8. Back from the displacement this flexure disappears by the decrease of dip, as shown in section 5, where the beds are horizontal one-half mile back of the fault, or in section 6, where a synclinal in formed. The general dip of the pre-Tonto beds is to the northeast. South of Chuar valley, beyond where the fault disappears, the strike of the strata is regularly to the northwest and southeast.

As determined from the section of the pre-Cambrian fault exposed to ex-

amination, its maximum throw was on the line of the greatest displacement by faulting during the Tertiary movement. It broke into branches and diminished in throw towards each end of the present Butte fault. This is not unexpected, as the Tertiary break was undoubtedly over and along the line of the least resistance below. It roughly duplicated the old line of faulting, only reversing the direction of the movement about 2,000 feet along the greater part of the fault. That the rocks of the Chuar terrane are still displaced from 400 to 2,000 feet, in relation to well-marked Algonkian strata, proves the profound character of the pre-Tonto fault. The movement probably occurred during the progress of the elevation of the Keweenawan continent, and when the Archean (?) and the 12,000 feet of Algonkian strata now unconformably underlying the Cambrian Tonto sandstone, were brought to the surface; the agents of erosion planed off the raised and faulted strata, and not until the remainder of the Paleozoic series, the Mesozoic, and much of the Tertiary were deposited, did any known movement occur on the line of the fault, except to form a slight monoclinal fold at or near the close of the deposition of the sediments of the Paleozoic. (See figs. 11 and 12.)

The Tertiary Movement.—This has been largely described in giving the details of the various sections, more especially those of section 4, where it is stated that the eastward throw of the combined fold and fault is fully 2,700 feet. That the latter movement took place in Tertiary time has been well established by Capt. C. E. Dutton, in his study of the High Plateaus and the Tertiary History of the Grand Cañon. In the following description of the flexing or upturning of the strata on the line of the fault, many descriptive details will be found that otherwise would be referred to under this heading.

Flexing of Strata on the Line of the Fault.—The area of pre-Cambrian strata exposed to view by erosion is limited, but from it we learn something of the general geologic structure of the pre-Cambrian surface and the conditions under which the flexing of the strata occurred in the vicinity of the Butte fault.

Eight miles southwest of the southern branches of the fault, the Archean (?) or older Algonkian rocks appear. Here the plane of their upper surface, over which the strata of the Grand Cañon group were deposited conformably,* and probably horizontally, strikes N. 35° W. and dips 10° to the N. E. The strata above partake of this strike and dip, and, with the exception of a broad undulation four miles to the northeast that forms a synclinal and anticlinal. This continues up to the vicinity of the fault. Continuing northwest of the immediate proximity to the fault, the general strike is west and northwest with a dip to the north and northeast, as far as the summit of the pre-Tonto groups at Nun-ko-weap butte, on the divide between Nun-ko-weap

* Not conformably to the strata of the Archean (?), as the greatest unconformity prevails in this respect.

and Kwa-gunt valleys. Two synclinal folds, with a north and south trend, have been crossed and the synclinal in which Nun-ko-weap butte rests has been entered. North of the latter the strata dip east and south to the limit of observation at the northern wall of Nun-ko-weap valley.

From Chuar lava hill, in Chuar valley, north to Nun-ko-weap valley, the pre-Tonto strata rise towards the fault on the west, sometimes to a limited degree, as in section 8, though more frequently the flexing embraces one or two thousand feet of strata that rise, with a more or less abrupt curvature, from a point half a mile or more west of the fault (see sections 4, 5 and 6). At the western fault of section 1, in Nun-ko-weap valley, the argillaceous shales rest against the hard lavas, sandstones and magnesian limestones, and bear no evidences of metamorphism. In Chuar valley the same thing occurs on the west side of the west branch of the fault; but the strata on the east side of the fault, forming the west slope of Chuar lava hill (section 8, P. T. fault) and the strata on the west side of the east branch of the fault (*a*, sections 8 and 9) are extensively altered. The lava flows of the western slope of the hill, with their interbedded and overlying sandstones, are turned downwards towards the fault. The sandstone is changed to quartzite; the lava is compressed, and so interbedded with the sandstone that the first impression is that a plastic mass has been pressed against, and dragged down, the slope. On the east fault, massive layers of sandstone have been altered to quartzite, and the lava beds curved up as readily as the more flexible interbedded sandy shales. The strata against which the metamorphosed beds were pressed, at the time of their metamorphism, are now concealed by the throw of the fault. Between Chuar lava hill and Nun-ko-weap valley the Tertiary movement has carried the pre-Tonto strata on the east of the fault entirely out of sight, bringing Carboniferous strata into contact with the pre-Cambrian Chuar series.

From these observations it appears that at the close of the pre-Cambrian period of deposition of sediments in this region, a change ensued that resulted in the uplifting, as we now know, of 12,000 feet of strata, between the summit of the pre-Cambrian terranes and the Archean (?); and also, a considerable portion of the Archean (?) to the southwest. During this uplift, or possibly later, a fault of considerable importance began on the line of the present Butte fault, displacing the strata with a downthrow to the west of from 400 to 4,000 feet in the area now exposed to view. This movement was probably prior to the planing to base level, by erosion, of the inequalities and irregularities of the surface produced by the undulations and faults in the pre-Tonto formations. The uplifting and metamorphism of the strata along the line of the pre-Tonto fault, could scarcely have occurred without the presence of sufficient superincumbent rock to give the lateral pressure necessary to produce the phenomena observed in sections 1, 4, 5, 6 and 7.

The Tertiary movement has not perceptibly influenced or changed the position of the upturned Algonkian strata. It was the reverse of that of the Algonkian, and strata of various degrees of firmness were flexed upward from the east. The massive Tonto sandstone curving slightly downward towards the fault from the west (fig. 10), indicates that a portion of the fold that preceded the Tertiary fault compressed the upturned Chuar shales, but did not materially change their position in relation to the plane of the fault.

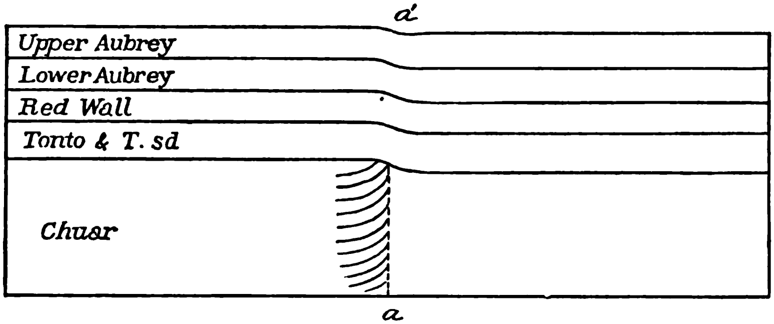


FIGURE 10.—*Ideal Section of East Kaibab Monocline.*

Illustrating the position of the strata on the line of sections 4, 5, 6, etc., before the breaking of the monoclinal fold, portions of which are preserved by the Tonto sandstone in sections 5 and 6.

The evidence of Tertiary flexing is clear and decisive. The massive Red Wall limestone, 900 feet in thickness, curves up and bends over, taking a westward dip, as seen in section 4. All along the line of the fault the sandstone, limestone and shales approach it at a high angle, and are frequently in a vertical position as well as more or less metamorphosed. The study of the probable conditions under which this upturning of the strata occurred is very interesting, and opens up questions that have a bearing on the history of the erosion of the Grand Cañon.

In the diagramatic section (fig. 11) the relative positions of the Aubrey limestone and sandstone, the Red Wall limestone, and the upper calcareous and lower sandstone series of the Tonto group, are defined on both sides of the fault. Dotted lines indicate the position of the strata on the west side, out to the fault line, prior to their removal by erosion. The Aubrey limestone has been eroded away in the immediate vicinity of the fault. The subjacent sandstone approaches nearer, and its upturned massive beds are shown in sections 4, 5 and 6. It is not, however, until the great Red Wall limestone is reached that immediate contact with the plane of the fault occurs. Here there is decided evidence of the lateral and vertical pressure accompanying the displacement. The upper limit of the Red Wall limestone has heen displaced, as shown in fig. 11, from x, on the west side of the fault, to x on the east side, a distance of nearly 1,300 feet. This

movement produced the upward flexing of the strata, as is shown in most of the cross-sections of the fault, as well as by the alteration of the Red Wall limestone. The latter formation received its flexure and local metamorphism in passing by the rocks of the same geologic age and also the Upper Tonto strata beneath, on the opposite or west side of the fault. There is no direct evidence that the Aubrey limestone was also flexed and metamorphosed, as it is now removed by erosion from the vicinity of the fault, but from the relations it bears to the strata below, as shown in sections 4, 5 and 6, and in fig. 11, there is little doubt that such was the case. This is almost absolutely proven by its partaking of the flexure of the fold, to the north, in perfect conformity to the strata beneath.

From these considerations and the present relations of the strata on the opposite side of the fault, as given in fig. 11, it is evident that the formations (Upper Aubrey, Lower Aubrey, Red Wall, Upper Tonto, and Tonto sandstone) had not been eroded, within the dotted lines, at the time of faulting.

On the slope of the East Kaibab fold, twenty miles to the north, the hard, compact limestones of the summit of the Aubrey group form the surface rock. The massive layers curve downward with the flexure of the fold, and often large slabs, detached by erosion, retain the curvature they received. When this flexing occurred there must have been a considerable thickness of strata above, exerting by its weight a powerful downward pressure. This necessitates the presence of the Permian and more or less of the superjacent strata over the east slope of the Kaibab Plateau and the Grand Cañon area. Whatever other conditions of slow movement and lateral pressure may have existed, a downward pressure, as above indicated, was also necessary in order to fold and flex the strata as they occur on the line of the East Kaibab displacement, both in the fold and on the line of the Butte fault.

The Butte Fault and the Grand Cañon.—It is stated in the preceding paragraph that in order to explain the curvature of the strata near the fault a considerable thickness of strata must have existed above the rocks now exposed to view. With a thousand feet or more of strata above the area now occupied by the Kaibab and the lower plateaus adjacent to the Grand Cañon, it is difficult to understand how the cañon could have existed even to a limited depth, in its present position, at the time of the elevation of the Kaibab Plateau. An explanation more in accord with observations on the Eastern Kaibab displacement is that while the uplifting of the plateau and the East Kaibab displacement were progressing, the Colorado river was cutting its channel down through the Mesozoic groups that then rested on the Paleozoic rocks in which the present cañon is eroded, and that, instead of cutting a channel down through the limestones and sandstones of the Paleozoic, as the plateau was elevated, it was cutting through the fold in the

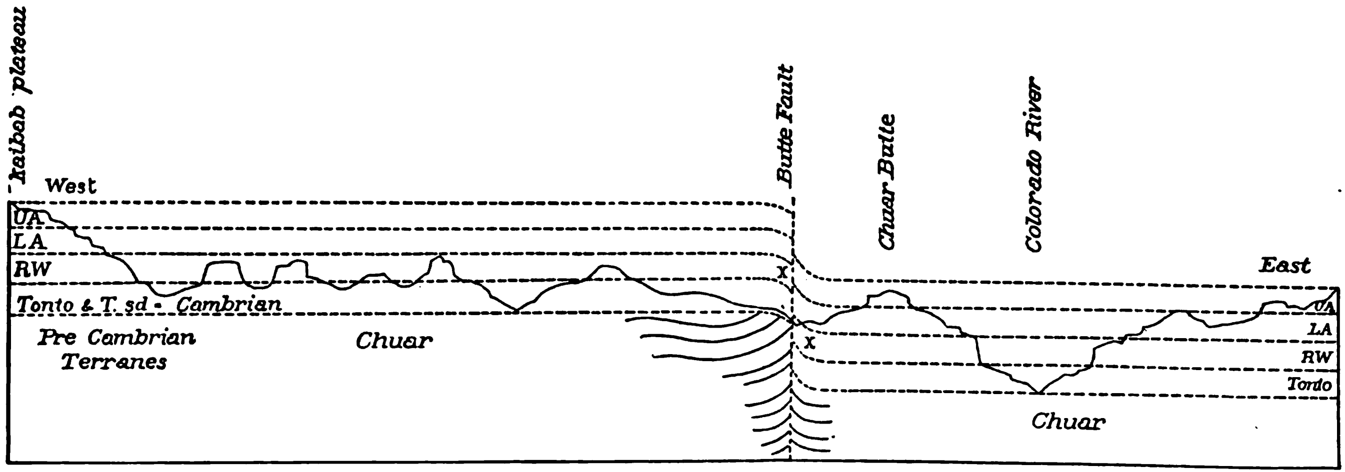


FIGURE 11.—*Section across the Cañon at the Chuar Butte, with Restoration of eroded Strata.*

superjacent Mesozoic rocks. This would influence the manner of the erosion of the Grand Cañon, and, if followed out in all its bearings, would probably necessitate some change in the now accepted views concerning the manner of the erosion of the broad outer and narrow inner cañons, west of the Kaibab division of the Grand Cañon. At present the influence of the Butte fault on the erosion of the area immediately adjacent to it will alone be noticed.

Fig. 11 shows that as soon as the river reached the limestone on the west of the fault, it would necessarily erode the softer strata on the east side until the summit of the Upper Aubrey limestone was reached. If near or on the line of the fault, the channel would be deflected eastward by the slope of the strata until it reached the base of the slope, leaving a strip of rock between the river channel and the fault line. The cliff left on the west side of the fault as the river deepened its channel, afforded the agencies of aerial erosion an opportunity to do their work rapidly, and the debris was carried to the river as soon as it fell on the limestone slope below. With the deepening of the river bed, channels formed between it and the retreating cliff, and the great buttes were marked off. Subsequent erosion deepened the channels to cañons and removed the strata on the west of the fault. When the base line of erosion once reached the friable and easily eroded argillaceous strata of the Chuar group, the cutting away of the inner cañon valley area advanced at a rapid rate, until the havoc and ruin was greater than that accomplished by the direct agency of the river in the cañon east of the buttes. To-day the buttes rise high above the inner cañon valleys and guard them from the ravages of the river, although they are 2,000 feet below the level of the Kaibab plateau.

Analogy between the Hurricane Fault and the Butte Fault.—The Butte fault is only paralleled in the Plateau country, as far as known to me, by a portion of the great Hurricane fault, north of the town of Toquerville, in southern Utah. The upturning of the strata is there on a somewhat greater scale, and it occurred in the earlier movement on the line of the fault, for the upward flexing is from the east and the present downthrow is to the west.

The downthrow of the Hurricane fault north of Toquerville is estimated by Captain Dutton to be over 6,000 feet.* The massive Aubrey limestone rises towards the fault from the east at an angle of from 25° to 30°, the western face of the flexed strata forming a more or less broken cliff 1,000 feet in height. To the north the shear of the fault increases rapidly. Ten miles distant it is estimated by Dutton at from 12,000 to 14,000 feet. The upturning of the strata from the east is also more marked north of Kanarra, where it curves up to the vertical and is even reversed so as to have a westward dip of 45° for a distance of several miles along the fault.

Captain Dutton states that the thrown beds, on the west side of the fault, curve down towards it. He explains this by the presence of a monoclinal

* Tertiary History of the Grand Cañon District, 1882, p. 113.

fold on the line of the fault that had a downward curvature to the east. The fault subsequently broke the fold and carried a portion of it down to the west. This satisfactorily explains the position of the strata on the west side of the fault; but another explanation is demanded for the eastern upturning and the reversal of the strata on the east of the fault. This is found in the data given for comparison, by the position of the strata in the sections of the Butte fault (figures 5 and 11). Figure 10 illustrates the position of the strata at the time of the monocline, of which Captain Dutton speaks; it being understood that the relative position of the strata in the two sections and not the same geologic terranes are referred to. In sections 5 and 11 the monocline is broken and the strata on the east dragged up towards the fault. This is the position which I think the strata on the opposite sides of the Hurricane fault, north of the site of the present town of Kanarra, occupied before the reverse movement, accompanied by the downthrow to the west, began. Erosion removed some of the upper strata, in all probability, but the general section would have been similar to section 10, the dotted lines representing strata present and not eroded as in the section of the Butte fault. The evidence of lateral and vertical pressure on the upturned beds, is the same as on the Butte fault. The subsequent downward movement on the west, or the more probable elevation on the east, was unaccompanied by sufficient lateral pressure to flex and reverse the position of the strata on the east side of the fault, in the vicinity of Kanarra.

Paleozoic Movement.—Before giving a summary of the history of the East Kaibab displacement, as interpreted in this paper, it is necessary to record the observations upon which the existence of a movement at the close of Paleozoic time is based.

West of the town of Paria, on the road leading from Paria, Utah, to House Rock spring, Arizona, the upper beds of the Permian rise with the curvature of the East Kaibab fold towards the west. The overlying Shinarump conglomerate, the base of the Mesozoic groups, also rises, but not so rapidly, and consequently thins out against the greater curve of the Permian. This is still better seen in a section through the fold exposed by an east and west cañon. Erosion, at the close of the Paleozoic, cut into the Permian and formed an eastward-facing cliff. The Shinarump conglomerate was subsequently deposited against and over this cliff, gradually thinning out to the westward and disappearing against the rising slope of the Permian beds. The cliff and the thinning out of the Shinarump are well shown in the section forming fig. 12.

The Shinarump does not appear again in the entire distance across the Kaibab fold. The massive upper stratum of brown sandstone capping the Permian is also absent, and the clays of the Permian and Trias are in conformable contact, no evidence of a stratigraphic break being discernable. From the fact that the massive upper stratum of the Permian also thins out

on the rising slope of the fold, I am inclined to think that the slight movement of this time was going on during the latter part of the deposition of the Permian.

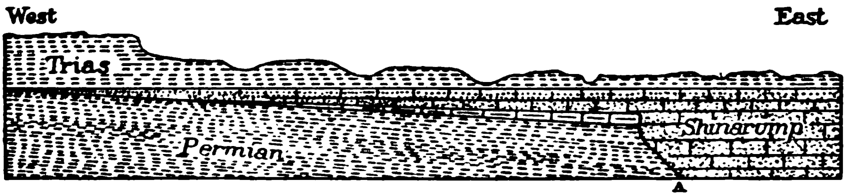


FIGURE 12.—*Diagramatic Section of the Permian Monocline.*

Illustrating the thinning out of the upper Permian and the Shinarump conglomerate against the more highly inclined Permian strata beneath. (The ancient Permian cliff is concealed by debris at the immediate base of the section.)

It is probable that the era of the deposition of the Permian was one of slow movement of the sea-bed. Elevation and depression are indicated by a strongly marked unconformity, by erosion, in the lower portion of the upper Permian. This is shown by the unconformity in the Permian so well seen in the buttes south of the Shinarump cliff, eleven miles southwest of Kanab, Utah. The sediments are mostly detrital in character, and ripple-marks and other indications of a littoral deposit are also seen at several horizons. The evidences of the movement do not indicate that it was of great magnitude, but rather the contrary. Sufficient is shown to prove that the inception of the great Tertiary displacement was in Paleozoic time.

From the close of the Paleozoic to the Middle Tertiary there is no known evidence of any movement along the line of the East Kaibab displacement. The intervening time appears to have been one of slow subsidence and quiet deposition of sediments. From the evidence given by Captain Dutton* it is scarcely to be doubted that the later displacements are of Tertiary age, and that the movement continued to a comparatively recent date.

Résumé.—The history of the displacement is briefly stated as follows:

The East Kaibab movement began in the region of the Grand Cañon as a pre-Cambrian fault displacing the older Algonkian strata, with a downthrow to the west of from 400 to 4,000 feet. A period of rest then ensued that was broken, in the latter part of Paleozoic time, by the formation of an eastward-facing monoclinal fold of a few hundred feet. So far as known this movement ceased with the close of the Paleozoic, and was not resumed until Tertiary time. It then began and continued until the East Kaibab fold and the accompanying fault were developed; the displacement aggregating over 2,700 feet in the vicinity of the Grand Cañon. This occurred before the removal, by erosion, of the Permian and probably more or less superjacent strata over the Grand Cañon area.

* Monographs U. S. Geol. Survey, vol. 2, with atlas, 1882; Tertiary History of the Grand Cañon District, p. 70.

THE HIGH CONTINENTAL ELEVATION PRECEDING THE PLEISTOCENE PERIOD.

BY PROFESSOR J. W. SPENCER, A. M., PH. D., F. G. S. (L. & A.),

STATE GEOLOGIST OF GEORGIA.

If, in the growth of the American continent, the moulding of the land features had not largely depended upon its projection above the sea, favoring or retarding the action of rains and rivers in sculpturing its surface, there would be little interest as to what was its relative height, before the commencement of the Pleistocene period. But we find valleys vastly greater than the meteoric agents could have produced under existing conditions. Thus, there are not only deep cañons, but also vast depressions, descending to levels far below the sea, which are now filled with the earlier drift accumulations, or form channels submerged beneath ocean waves, or constitute basins occupied by lakes. Hence, in the study of the drift itself, in the investigation of the lake history, or in the research upon the growth of modern rivers, we necessarily inquire what was the altitude of the continent that would permit of the mouldings and channelings of the original rock surfaces.

Following the period of high continental elevation, the geologist sees in the valleys and old channels, still below the level of the sea, and in the high level beaches, an extensive submergence, succeeded by a re-elevation, but not to the original height, when the continent was being chiseled out by the ancient rivers. That this re-elevation is still going on is shown by the northward tilting of the comparatively recent marine accumulations along the St. Lawrence valley and Gulf coast, and the raised beaches in the lake region, as well as by the shoaling of the waters of Hudson's Bay during the present period of observation.

As general statements do not satisfy investigation, it becomes necessary to search for definite measurements of the former height of the continent among the archives of the geological past. Let us first seek for the testimony recorded by the Mississippi river.

For the distance of eleven hundred miles, measured in a direct line, above the mouth of the "Father of Waters," the modern valley is merely maintaining its own size, or more generally is being slowly filled by the deposition of river alluvium upon its floor. There are only two exceptions, of a few miles each, where the river is scouring out the rocky floor, and these are over barriers recently exposed there during changes of the Pleistocene

period. To such an extent has the ancient valley or cañon been filled, first with drift, and this covered with river alluvium, that its original rocky floor is now buried to a depth of 170 feet, even at La Crosse, a thousand miles from the Gulf of Mexico.* Farther south the depth of these loose deposits increases, until at New Orleans a boring of 630† feet below sea level does not penetrate the southern drift, nor even reach to its lowest members. The lower 500 miles of the ancient Mississippi were excavated out of Eocene or Cretaceous deposits, whilst the valley above the mouth of the Ohio has the form of a cañon, excavated out of Paleozoic rocks, varying in width from ten to two or three miles, and having a depth (exclusive of the portion now filled) of from 150 to 550 feet, according to the late General G. K. Warren.

From this inspection of the river, it is easily seen that no natural rainfall could so increase the volume of the discharge as to remove all the deposits which now fill the old valley, much less excavate the original and immense cañon. A vastly greater elevation of the continent was necessary. Even were the whole continent uniformly elevated 630 feet, together with the remainder of the unknown depth of the ancient Mississippi river, at New Orleans, the cañon of the upper part of the river would require a still greater relative elevation of the northern country in order to give sufficient channeling power to the flowing waters; but the slope of the floor of the partially buried valley is much less than that of the modern, as was formerly shown by the author.‡ Here, again, is the proof that the country drained by the upper waters of the Mississippi once stood, relatively to that in the region of its mouth, much higher than at present. Of the amount, which was at least many hundreds of feet, we have no absolute measurement; nor can we ascertain it by calculation, for there is no register of the excess of the amount of rainfall during the epoch of the greatest sculpturing over that of the present day.

Whilst these records of the Mississippi, which have been only partially deciphered, do not furnish all of the desired information, yet as far as they go they are invaluable.

Passing from the buried channel of the Mississippi to its continuation, now submerged beneath the waves of the Gulf of Mexico, we find evidence indicating such a stupendous continental elevation as to be almost incredible, were it not supported by collateral evidence, upon both the Pacific and Atlantic coasts. The soundings off the coast of the delta of the Mississippi indicate the outer margin of the continental plateau as submerged to a depth of 3,600 feet, indented by an embayment of another hundred fathoms in depth, at the head of which there is a valley a few miles wide, bounded by a plateau

* Geol. Wis., Vol. I, 1883, p. 253.
† E. W. Hilgard, Am. Jour. Sc., 2nd Ser., Vol. XLVIII, 1869, p. 333.
‡ Am. Nat., Vol. XXI, 1887, pp. 168–71.

from 900 to 1,200 feet above its floor. This valley is now submerged to a depth of 3,000 feet, and is the representative of the channel of the ancient Mississippi river, towards which it heads.*

On the Pacific coast, in the region of Cape Mendocino, Prof. George Davidson has identified three valleys now submerged to from 2,400 to 3,120 feet, and several of inferior depth. These measurements are those of the valleys where they break through the marginal plateaus of the continent, at about six miles from the present shore, where it is submerged to the depth of a hundred fathoms.†

The soundings along the Atlantic coast reveal similar deep fjords. The long-since known extension of the Hudson river, beneath the Atlantic waters, is traceable to the margin of the continental plateau, acquiring a depth of 2,844 feet, in front of which the soundings show a bar, covered with mud, which however is now submerged to the depth of only 1,230 feet. The unpublished soundings off the mouth of the Delaware river bring to light another valley, the floor of which is now covered by ocean waves to nearly 1,200 feet—its continuation seaward not having been ascertained.‡

Were the continent elevated only 600 feet, the Gulf of Maine would be replaced by a terrestrial plain, in some places 200 miles wide, but traversed by rivers, one of which, towards its mouth, would be 2,064 feet deep—that is to say, the bottom of the fjord is now submerged 2,664 feet. Even this great depth may not be its maximum, for along the line between the opposite banks, at the mouth, now beneath a hundred fathoms of water (which is approximately the depth to which the real margin of the continent is submerged), we find that the sea is nearly 5,000 feet deep. Whether this represents an embayment of the ocean setting towards the valley or a continuation of the fjord is not determined.

The St. Lawrence river and gulf bear the same testimony of the existence of deep fjords extending from the rivers through the now submerged plateau forming the margin of the continent; and the lower part of Saguenay river flows between stupendous walls and constitutes a fjord whose waters reach a depth of 840 feet. In the St. Lawrence river, a little below the mouth of the Saguenay, there is a channel 1,134 feet below the surface. This increases in depth in passing seaward. In the region of the centre of the modern gulf, the floor of the old channel is now submerged 1,878 feet, and the adjacent valley 1,230 feet; thus showing the cañon as being over 600 feet deeper. As at the mouth of the channel through the Gulf of Maine, so at the mouth of that of the St. Lawrence, there is a deep chasm; for enclosed between the banks, a hundred fathoms below the surface, there is now the depth of 3,666 feet, with water 2,000 feet deeper just seaward of

* J. W. Spencer, "The Mississippi River During the Great River Age," New Haven, 1884, p. 2.
† Geo. Davidson, Bull. Cal. Acad. Sc., Vol. II, 1887, p. 265.
‡ Appendix 13, Rep. U. S. Coast and Geodetic Survey for 1887 (1889), pp. 270–73.

it. Although this ancient valley is over sixty miles wide at its mouth and was a narrow channel, yet it is not as broad as some portions of the modern

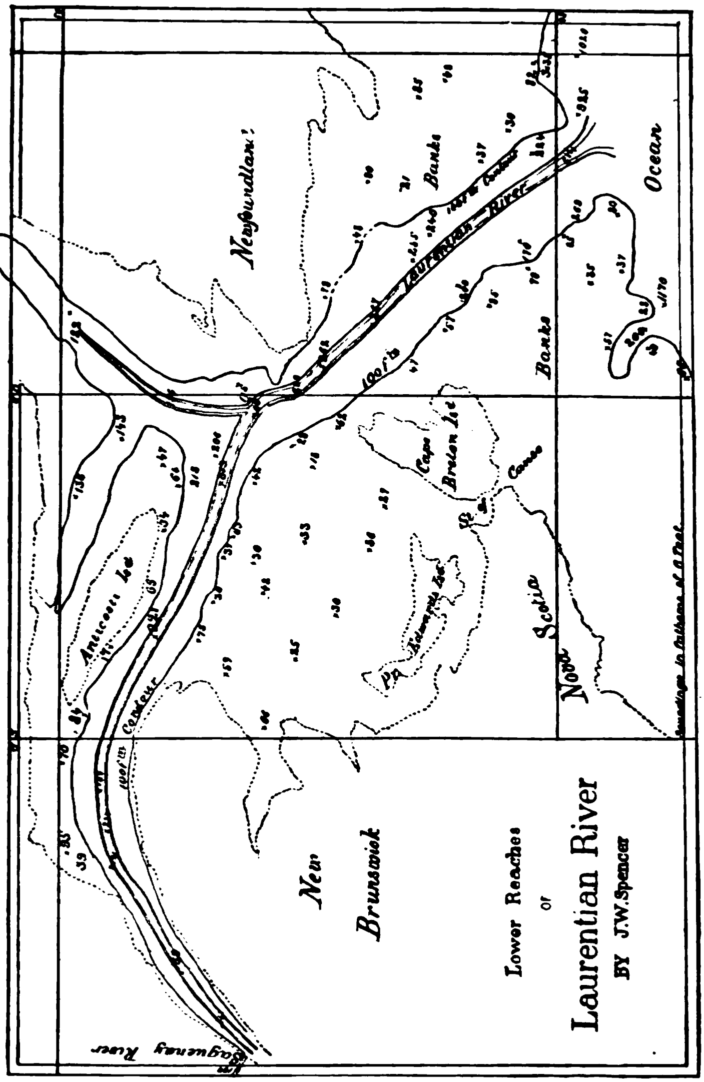


FIG. 1.—*Map of the Gulf of St. Lawrence, showing the course of an ancient river.*

so-called river. The breadth of the submerged valley throughout its windings for a length of 800 miles or more, is remarkably regular, only gradually increasing its magnitude in passing seaward. Other and lesser channels are visible in the soundings: thus, south of the Straits of Canso, between Nova Scotia and Cape Breton island, there is one 1,200 feet deep, according to the

British Admiralty charts, while adjacent soundings show less than 600 feet of water.

Hudson's Bay rarely exceeds a depth of 600 feet, yet at the outlet the channel is 1,200 feet deep. This depth increases in passing down the straits, where the scanty soundings show 2,040 feet before reaching the mouth. Here, in Hudson's Straits, the old valley is a chasm across a mountain system, whose peaks, upon the southern side rise to 6,000 feet above tide. The cañon of the St. Lawrence also crosses the trend of two mountain systems, but these are of no great height. The same is not true for any of the other submarine valleys described.

The record of a former high continental elevation is again inscribed in the depths of the Great Lakes—Ontario reaching to 491 feet below ocean level, Superior to nearly as much, Michigan to 300, and Huron to 150 feet. The lake basins are merely closed up portions of the ancient St. Lawrence valley and its tributaries. Their distance from the sea would necessitate not merely a general elevation of the continent, but also a greater amount of elevation towards the head-waters of the system, as has been shown with regard to the excavation of the upper portion of the ancient Mississippi cañon. The lake basins are all excavated out of Paleozoic rocks, except a part of that of Lake Superior.

The soundings do not afford all the information that we desire, yet they demonstrate the presence of submarine valleys reaching upon all our coasts to depths of 3,000 feet or more. Again, the soundings show that within comparatively short distances from their mouths the depth of the valleys, below the surface of the seas, sometimes did not exceed from 1,200 to 1,800 feet, but that beyond, there was a greater increase in depth, within the last few leagues.

Whilst depressions in the earth's surface are made and modified by terrestrial crust movements, yet the leaving open of great yawning chasms is not of sufficiently well known occurrence to attribute all of the submerged valleys upon the American coasts to such an origin, especially when we consider the great length of the submerged channel of the St. Lawrence river (800 miles), its various windings, and its uniformly increasing size, until it passes into the great chasm, just before it reaches the margin of the continent. The idea of the excavation of these submerged valleys by glaciers—some of which are outside of glacial regions even of the past—is too untenable for a moment of serious consideration. Irrespective of the causes which have determined the location of the channels here described, it appears that they have been made one and all by the excavating power of rivers and lateral streams pouring down the hillsides. These, together with the other meteoric agents, have also to a greater or less extent removed the Paleozoic, and also the Triassic rocks, from the depressions now occupied by the Gulfs of St.

Lawrence and Maine, which have, however, been more or less affected by terrestrial movements.

The length of time required to excavate the channels of these great rivers commenced as far back as the Paleozoic days. However, the culmination of that of the Mississippi was not until in the later Tertiary, before the Pleistocene period. As the St. Lawrence, now submerged to a depth of over 1200 feet for a distance of 800 miles, is mostly cut out of rocks of the Paleozoic group, except a belt of the Triassic (across the lower portion, more or less involved in mountain uplifts), its antiquity must be very great. The culmination was also probably in the later Tertiary era, like that of the Mississippi, and the channels on the California coast, for there are submerged Tertiary rocks off the coasts of Massachusetts and Newfoundland, at elevations much higher than the beds of the old channels.

Although the excavating forces took so many periods to form the valleys, and required a high continental elevation, yet the extreme altitude of over two thousand feet appears to have been of comparatively short duration, for otherwise the deep chasms in which the submerged channels terminate would have extended farther inland than we find them, and would have been headed by more gentle slopes, in place of precipitous cliffs, over which the waters of the former rivers were precipitated in great cascades. In the fjords of Norway, merging into rapidly contracting valleys, or headed by great vertical walls, hundreds of feet in height, having the structure named cirques, may be seen to-day the counterpart of the coast of the American continent, when its marginal plateaus stood 3,000 feet higher than at present; yet Norway stood once much higher than now, but was afterwards submerged, from which depression it has only recently been re-elevated so that its plateaus, close upon the sea, rise to three or four thousand feet, and its mountains still higher. The old hydrography is more or less distorted by warpings of the earth's crust, which, however, do not obscure the valleys, although rendering the features somewhat more complex. The amount of distortion has yet to be determined.

University of Georgia, August, 1889.

ANCIENT SHORES, BOULDER PAVEMENTS, AND HIGH-LEVEL GRAVEL DEPOSITS IN THE REGION OF THE GREAT LAKES.

BY PROF. J. W. SPENCER, M. A., PH. D., F. G. S. (L. & A.),
STATE GEOLOGIST OF GEORGIA.

CHAPTER I.

CHARACTERISTICS OF ANCIENT SHORE-LINES IN THE REGION OF THE GREAT LAKES.

The land features throughout the lake region drained by the St. Lawrence river owe their formation largely to the action of waves, sculpturing rocky or modeling earthy shores. That the waves have not always been confined to the margins of the modern lakes is seen in the sea-cliffs and beaches, from which the waters have long since receded. These features, still remaining, are sometimes in the form of bold relief, and sometimes in the form of narrow sand or gravel ridges, delicately traced over a flat country. In some places these ridges approach near to the lakes; in other localities they are miles away, and at varying altitudes up to hundreds of feet above their present waters.

The raised shore-lines are no longer water levels, for terrestrial movements, since the lakes have receded from them, have commonly lifted them up to unequal altitudes. Whilst some of these old shores represent former lake boundaries, there seems to be little reason to doubt that the higher sea-cliffs and beaches formed the coast of brackish water inlets or arms of the sea.

Besides the deformation arising from the unequal terrestrial movements, the shores have been in many places defaced by the action of rains, rills, rivers, and landslides, until their broken continuity renders them somewhat difficult to follow over long distances. The object of this chapter is to describe the characters of the old raised and deformed water-margins, by which they can be identified. The ancient coast-lines differ in no respect from the modern, but they are often easier to follow, as there are no waters to restrict one's footsteps. Were the lakes to be suddenly drained, but a few years would elapse before the deserted margins would be as difficult to mark out with precision as any of those from which the waters have long since receded.

With notable exceptions, the lakes are generally bounded by banks of clay or sand, stratified or unstratified. The waves have in places cut into

these deposits, leaving high clay bluffs; in other localities the coast rises gently from the water-line. In front of these shores, whether high or low, beaches often occur. The typical beach forms a ridge of stratified sand and gravel, rising from three to five feet, or even more, above the surface of the water. The ridge may vary from a few yards to as many scores, or even hundreds. In the more perfect form, there is a slight depression behind the ridge which is sometimes occupied as a bay, lagoon, or swamp (fig. 1).

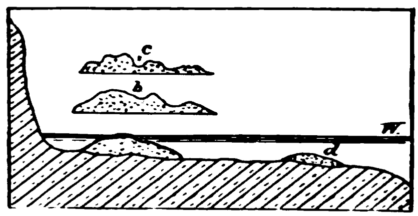


FIGURE 1.—*Section showing the Floor of a Cut Terrace on which rests a Beach.*
b and *c* = Beaches broken into ridgelets. *d* = A frontal sand bar. *W* = Old water-level.

Whilst the beach may form a frontal barrier, in shallow water, distant from the shore, it may rest directly against the coast, forming a terrace (*a*, fig. 2), behind which there is no depression. In this case the surface of the terrace is apt to be defaced by landslides or washes; but the beach, whether in the

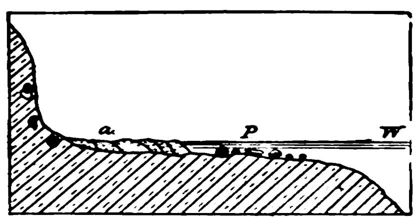


FIGURE 2.—*Section showing the Floor of a Terrace of Construction.*
a = Terrace of construction resting on cut terrace. *P* = Frontal pavement of boulders. *W* = Old water-level.

form of a terrace or off-shore barrier, is very often wanting when the currents are cutting into and washing away the coast (fig. 3). Under such a condition, if a beach be formed, it is narrow and temporary, as it is liable to be washed away or covered by landslides. The eastern and southeastern coast of Lake Huron commonly illustrate the absence of true beach structure. Another excellent example may be seen at Scarboro heights, a few miles east of Toronto, on Lake Ontario, where the clay banks rise to the height of more than 200 feet and extend for a distance of nine miles. Here the cliffs are being eroded. The waves are not forming a permanent beach, but the currents are drifting the materials several miles to the west to build up the barrier-beach in front of Toronto harbor.

In the formation of beaches there is a tendency to straighten crooked coast-lines by the construction of bars in front of inlets, which are thus converted into bays or lagoons. Burlington bay, at the western end of Lake Ontario, is an illustration. Here, a narrow beach (fig. 5) cuts off a bay five miles long, whose depth is considerable, reaching to 78 feet. This is a particularly well-chosen example, for at the head of the bay there is a spit—named Burlington heights (*h*, fig. 5), rising to 108–116 feet above the lake—

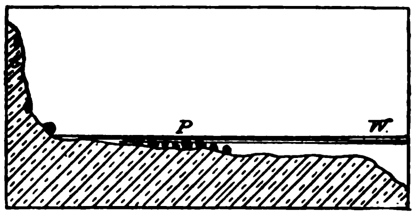


Figure 3.—*Section showing the Floor of a Cut Terrace without Beach but with Boulder Pavement.* P = Boulder pavement. W = Old water-level.

cutting off an older bay, now represented by the Dundas marsh. This spit, when the waters were at its level, formed a portion of an ancient shore (to be described in a future chapter) in the same manner as Burlington beach forms a portion of the modern lake-shore.

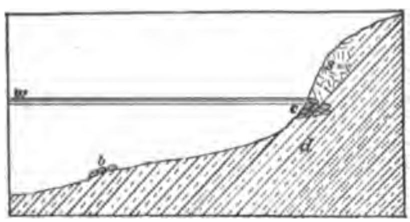


Figure 4.—*Section showing a Cut Terrace with a fragment of Old Beach partly concealed by a Landslide.* b = Boulder pavement. c = Fragment of old beach. d = Drift. s = Landslide. w = Old water-level.

In places, where the waves break upon the more exposed coast, the beaches are apt to be piled up a few feet higher than their mean level. The opposite result is seen where the ridges are fashioned as spits and pass below the surface of the water in the form of submerged bars. The increase in the depths of the water in front of the beaches is usually very gradual.

The study of the modern and ancient shores is reciprocal. By the former, still washed by waves, we can identify the latter; and by the examination of the floors in front of the raised beaches, we can more fully understand the action of waves upon the modern coasts, than where the subaqueous deposits cannot be seen. The muds, derived from the encroachment of the waves upon the land, are assorted; the coarser materials being those which form the

beaches, and the finer clay, that which constitutes the off-shore silt deposits, leveling up the inequalities of the lake bottom and forming very flat submerged plains, which are rendered apparent upon the withdrawal of the waters.

In the examination of old shores, the occurrence of flat or very gently inclining plains, abutting at constant levels against rising hills, is as certain an indication of old coast-lines as if beaches were found there; but the exact height of the water-line cannot be recognized, as the water may have been five or it may have been twenty feet deep. When this condition obtains, there may remain here and there a fragment of a temporary beach (*c*, fig. 4), covered by a landslide (*s*, fig. 4), but exposed by a stream or artificial cutting into the hillside, or there may be a barrier in front of an ancient bay or lagoon (*h*, fig. 5).

Whilst the greater proportion of the lake coast is composed of drift deposits, there are places where the water-margins are bounded by rocks. Here the structure is similar, although not so well developed, and the banks may assume the form of vertical cliffs. Generally speaking, the beaches in

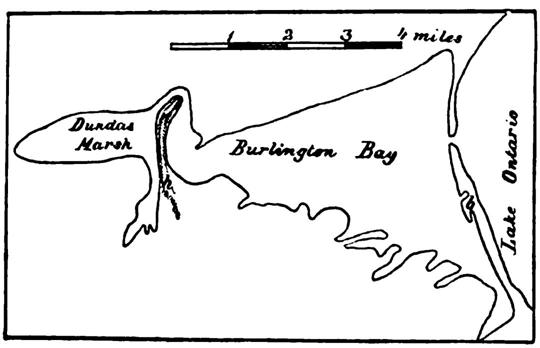


FIGURE 5.—*Map of the Western End of Lake Ontario.*

b = Burlington beach, separating Burlington bay from the Lake. *h* = Burlington heights, an ancient beach 108–116 feet high, separating Dundas marsh from Burlington bay.

front of these rocks are not so well developed as where there have been shore deposits of boulder clay to supply the waves with pebbles. However, some of the higher and older coast-markings remain in the form of such "sea-cliffs," in front of which there are comparatively flat plains.

Another structure, when present, is very characteristic of many portions of the ancient shores, or, indeed, is occasionally seen in front of the modern beaches. This is a pavement of boulders (derived from adjacent shores of boulder clay), occupying a given zone (*P*, figs. 2 and 3). This zone is in front of and a few feet lower than the level of the true beach; the boulders having been left just below the water-level as the waves made encroachments upon the coast. Again, the boulders have been more or less pushed up to

this line by the waves forcing up the coast-ice to which these boulders have been frozen. When these deposits occur adjacent to the modern beach, they may be seen rising out of the water, but they are also found outward in the lake to the depth of several feet (Plate 1, fig. 1).

In front of an elevated shore, the boulders may be arranged in the form of a zone, even a few hundred yards in width, throughout a vertical range of a few feet, which may be increased to thirty or forty feet where there is a succession of beachlets close together, marking the gradual recession of the waters. But the upper level of these zones never quite reaches that of the beaches. In travelling along a flat country these pavements of boulders are as certain indications of shore-lines as are any other forms of the beaches (Plate 1, fig. 2). Boulders left on the hillsides by the action of rains, washing out the finer materials of the drift clay, are not arranged in belts of symetrical level. The boulder pavements do not usually occur where the adjacent coast is not composed of boulder clay, nor where the beaches are separated from the land by what is now or has been a bay or lagoon. Pavements of boulders are not as commonly seen in front of modern shores as in front of some of those more elevated and ancient.

Turning to the more typical form of the beach structure, as shown in the raised shores, there may be seen sand or gravel ridges, most frequently from one hundred to sometimes five hundred feet across, rising to fifteen or twenty-five feet above a flat or very gently descending plain, whose surface is most commonly composed of fine clay. Sometimes this descent is so very gradual as to be inconspicuous; at other places the descent is quite sudden. The depression behind the ridge is generally less than that in front of it, and here also the floor may be composed of clay. When the beach is broad, it is apt to be broken up into a number of ridgelets (*c*, fig. 1). Indeed, some of the larger and more important beaches mark the recession of the waters by separating into several ridges, often at considerable distances apart, each a few feet below the preceding, where the lake floor is sloping very gently; but where the slope is more rapid, all unite into one large ridge. The beach has rarely a thickness of more than fifteen or twenty feet, and rests upon the clay or drift deposits, which constituted the floor of the former lake. As the plain recedes from the shore, the materials become finer and finer clay and freer from sand; but at varying distances, of sometimes a mile or more in front of the beaches, there may be found thin belts of sand resting upon the lake deposits. Again, the beaches may take the form of terraces of construction, resting against clay banks; or against these banks the ridges may abruptly (but only temporarily) end like the modern beaches (*b*, fig. 6).

In measuring the comparative altitudes of a beach at different points, the summit of a well marked ridge should be chosen, rather than that of the beach in the form of a terrace (*a*, fig. 2) against the shore, or the junction

of the coastal plain back of a cut terrace (*c*, fig. 4) and the bounding hills, as the exact water-level can here be only approximately determined. It is more accurate to make the calculations as to the former water-levels from the top of the ridges than from the foot of the beaches, as the slope in front

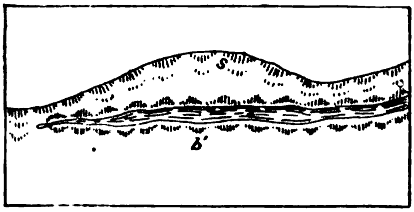


FIGURE 6.—*Plan of Barrier Beach in front of a Lagoon and overlooked by Hills.*
b=Line of Hills. *s*=Barrier Beach. The beach ends abruptly on the left.

of them is steep in one place, and in another very gentle, but the summit is easily recognized. Where the beach itself is absent, by tracing the coastal line, there will be found sooner or later, a bar or spit in front of some river or extinct bay.

In ascending from the modern lakes to the highlands, several old shores must be crossed. The country may be described as a series of terraces or steps, whose frontal margins are moulded into hills, and whose surfaces are plains, most commonly of clay, although sometimes of gravel or sand, at the back of which, there may be found the beach in some form. These gently rising terrace plains may each be several miles in width—and consequently the beaches several miles apart—or they may be narrow with the beaches close together. In many regions, the old shores behind these plains rise and extend across the country as conspicuous ranges of hills. The plains themselves are occasionally eroded by streams, until the whole country is very broken. This is more likely to be the case with terraces of the greater altitudes, and here the more recent surface erosion has often rendered the ancient shore lines hard to follow.

In crossing a series of beaches, the lowest is found to be composed of the finest gravel, or indeed perhaps of sand. In this case it is apt to be more or less heaped into dunes, by the action of winds. The ridges are often divided, but the branches unite again, or else send out spits ending abruptly. Occasionally the materials from which the beaches were formed was stony sand, in place of stony clay. Here, then. the extinct water-margins are difficult to determine, for there is no sharp lithological character, as where a beach crosses a clay plain—to mark the boundary between the sand beach—commonly heaped into hummocks or dunes—and the frontal plain composed of sand.

Many of the upper beaches overlie drift deposits, but those of the lower elevations are more likely to rest upon stratified clay—the sediments carried into the deeper waters whilst the lakes were at higher altitudes. The character of the materials underlying the beaches is commonly the same as that forming the surface of the plain in front of the ridges; but its structure is best shown in sections exposed by the subsequent erosion where streams cutting through the ridges cross the plain. When such streams have been large rivers, as has often been the case, there may be some trouble in tracing the continuity of the beach, especially across a broken country, as a portion of the valley may be older than the beach, which may swing around and skirt the embayment, or form a bar across it. Or again, the beach may be only represented by conical or other shaped sand or gravel hills, which were delta deposits at the mouth of a former river. Such delta deposits may not rise to the level of the former body of water.

With the varying conditions here set forth, which the shore-lines undergo, the traveller, in coasting around the old lakes, can rarely proceed more than a few miles without meeting obstructions. When the beaches are a considerable distance apart, with perhaps only fifty or a hundred feet of difference in their altitudes, there is a liability of getting off one series and upon another. Consequently it is often necessary to resort to accurate levelling, allowing for reasonable variations in the height of the beach, and the differential elevation of the region, since the waters have receded from the former shores.

In some regions the former expansions of the lakes were occupied by archipelagoes. Consequently, there is an absence of continuous beaches, and the explorer must depend upon following the plain, which formerly constituted the lake-floor, finding here and there a fragment of the ancient beach, either upon the coast of the mainland or upon that of an island. Here again, it may be necessary to resort to accurate leveling to identify the beaches.

Whilst steep coast-lines may be followed through wooded regions, it is most difficult to trace satisfactorily a beach across such a country. The greatest difficulties are found where the ancient beaches enter regions that are composed of hills of crystalline rocks, more or less wooded, and interspers d with numerous lakelets. In such places, there are numerous gravel hills whose relationship to the old shores is not readily discernable.

In some places, the surface of the beaches is composed of nearly clean gravel or sand; elsewhere, from some admixture of clay, it becomes more or less earthy soil, to a depth of two or four feet, somewhat obscuring the beach structure. Again, there may be coarse stones resting upon its surface, as if these had been forced up after the beach had been formed, by a slight rise of the waters, or by the action of coast-ice, pushing them up. However, these must not be mistaken for the more ancient gravel beaches,

covered with drift, such as frequently exist, and will be described in another chapter.

The beaches, in the form of narrow belts of gravel or sand, crossing a flat country, were in many places used as trails by the Indian aborigines, and in some places these trails have been turned into roads, as they are always dry during the muddy seasons. These ridge-roads have attracted attention as ancient beaches for nearly a century. But the water long since withdrew from them owing to the elevation of the continent, which has been accompanied by their distortion from the water-plain, on account of an increasing rise to the north and east.

The great geological value of investigating the raised and ancient coast-lines lies, not only in gaining a knowledge of the former expansions of the lakes and their relationship to each other, but particularly in being able to make use of them, as old water-levels in order to measure the amount of deformation or warping of the earth's surface caused by terrestrial movements, resulting in the development of the basins of the lakes themselves, and other features. Whilst the old shore-lines record a great amount of unequal terrestrial movements, yet these movements have also left records in the older sea-cliffs.

Chapter II.

Boulder Pavements and Fringes.

In many localities of the northern part of our continent, the land surfaces are almost covered with loose boulders, varying from the size of cobble stones to masses commonly three or four feet long. Occasionally the blocks have a length of eight feet, but rarely longer. Whilst some of the boulders are angular blocks of Paleozoic limestones and sandstones of local origin, the greater proportion are Archæan rocks, which have been transported from the Canadian highlands, north of the great lakes, to a distance of sometimes three or four hundred miles. These crystalline rocks, although so hard and compact, have the angularities invariably removed. Blocks are frequently seen at altitudes of hundreds of feet above their original sources. Throughout the lake region, and the country north of the line of the southern limit of the drift, which is often fringed with them, the accumulation of boulders is not uniformly distributed. The country enclosed by that line is occupied by sheets and ridges of drift materials, through which the subjacent rocks occasionally protrude. Again, these plains and hills have their surfaces moulded by the action of the waves of vanished seas or shrunken lakes, often fashioning the region into a succession of broad terrace flats and hilly coast-lines. It is upon the surfaces of these moulded features that the boulders are found. Whilst there are vast areas where there is not a single

stone to be seen, and others where only an occasional block occurs, as if dropped down from some meteoric source, there are other localities literally so covered with large boulders as to prevent agricultural pursuits. These boulder accumulations are superficial and do not penetrate the subjacent earths. They occur along certain zones, outside of which they are not found.

The presence of these surface boulder accumulations has been most commonly explained alike by those who believe in the glacial origin of the drift and those who do not, as having been dropped by melting icebergs at the close of the drift epoch. A few glacialists regard these boulders as having been deposited from glaciers where they now rest. It has also been hinted that they have been left upon the hills, as the finer materials of the boulder drift have been washed away by atmospheric agencies; but it was only since the recent systematic studies of the high-level beaches, compared with modern lake shores, have been made that the natural explanation of boulder pavements and distribution of erratics become possible.

There are three conditions under which boulder accumulations are found. The most important is where the boulders form pavements stretching as belts across a level country, usually in front of ridges which once constituted old shore-lines, or forming zones of stones resting upon hillsides or capping the summits of ridges. Of lesser importance is the occurrence of blocks scattered sparsely and irregularly on the sides of hills. Lastly, occasionally erratics are found alike over the hilly and over the flat country. That the boulders were brought from their original sources in the later Pleistocene days and dropped by either icebergs or glaciers where we now find them is an untenable hypothesis, for their birth places are now often covered with the older drift or are hundreds of feet below the elevations where they are now found. The relation of the boulders to the older drift are such that the erratics can commonly be recognized as of secondary origin, being derived from the earlier accumulations of boulder clay or sand. The manner in which the blocks have been brought to the surface has been by the removal of the finer earths from the drift, principally by the action of the waves or currents encroaching upon the hills or ridges of such materials, charged with occasional boulders. Thus the coast-line has been moulded into steep shores, in front of which there is the gently descending plain, once submerged—the floor of a terrace since the recession of the waters (figs. 2 and 3).

Thus the boulders throughout the whole thickness of the drift, which were too large for transportation by the waves, were reduced to water level and were accumulated upon the floor in the form of pavements or fringes along the former water-margins. The removal of the earth beneath the boulders continued until they had settled to the maximum depth of wave

action below the surface of the water, for at greater depths the fine earth would not have been removed from beneath the stones. The vertical range of the fringes is from fifteen to twenty-five feet or more when the recession of the former waters was gradual, leaving a close succession of beaches. The width of the pavements varies from a few hundred feet to perhaps a half a mile, according as the slope is somewhat steep or very gradual. When the finer materials were entirely washed out into deeper water, then the margins of the plains, at the foot of the old coast-line, are simply fringed with boulders; but when the finer materials were assorted by the waves and currents, the sands and gravels have been formed into beaches, usually a few feet above the level of and behind the boulder belt.

But the story of the boulder pavements and fringes is not yet complete. Coast-ice has also played an important part in the arrangement of the paving stones. The waves, acting upon the coast-ice wherein boulders have been entangled, cause the stones to be forced up into more regular zones, as to height, than would be affected by the residuary deposition alone, as just described. Blocks of large size can thus be moved, not merely by the heaving action of modern frosts, but by the action of coast-ice itself; for boulders upon the margins of the St. Lawrence river, weighing seventy tons, are known to have been shifted by the spring movements of a winter's ice. Again, the writer has seen upon some of the shores of Shoal lake, in Manitoba, situated in a flat drift-covered country, modern beaches composed of huge boulders, piled up by the waves of the lake acting upon the ice in which the stones were enclosed, as otherwise blocks four or six feet long could not be gathered from the shores of the lake and accumulated into beach ridges, nor could they have been residual pavements as above described, for no high shores of boulder clay occur into which the waves could have made encroachments.

An excellent illustration of the modern formation of boulder pavements and fringes may be seen upon the shores of Georgian bay, between Thornbury and Collingwood, as shown in Plate 1, fig. 2. There the lake waves are encroaching upon a shore composed of boulder clay. The larger stones standing out in the water are too heavy to be materially affected by the waves or ice action. Excellent illustrations of boulder zones are found a short distance from this locality, at an elevation of 187 feet above the lake, as shown in Plate 1, fig. 2.

Other examples of fringes of boulders high above any modern waters may be seen a few miles beyond the eastern end of Lake Ontario. The same is true upon the northern side of the lake, as for example, back of Trenton and westward; these are parts of and in front of the finer gravels of an old beach, now more than four hundred feet above the lake. Westward of Toronto, where the old shores are of Paleozoic rocks, in place of drift, the boulder pavements disappear from the front of the beach.

FIG. 1.—MODERN BOULDER PAVEMENT ON GEORGIAN BAY,
EAST OF THE END OF BLUE MOUNTAINS OF COLLINGWOOD, ONT.

FIG. 2.—ANCIENT BOULDER PAVEMENT OF ALGONQUIN BEACH
(whose crest rises 187 feet above Georgian Bay) upon the N. E. side of Blue Mountains of Collingwood, Ont.

Upon the steep hillsides, as along the Mahoning valley, near the crossing of the Ohio-Pennsylvania line, there are zones thickly covered with boulders. There we find the records of old water-margins, as well as in the pavements associated with the well marked beaches and shore-cliffs facing the lake basins. The finer materials have been washed out of the associated drift to form bars, in the valley, which was once filled with water. On some of the higher hills between the southern part of Georgian bay and Lake Huron, to the west, the tops of ridges are covered with boulder pavements. These ridges were islands in a former expanded lake or sea, whose surfaces were encroached upon by the waves, until they were reduced to partially submerged reefs covered with great erratic blocks, as the finer mud was borne into the deep water. That these were island shores may be seen from the boulder covered ridges, although miles apart, being reduced to a common altitude.

On the hillsides, behind the fringes, there are only here and there irregularly deposited blocks, exposed by the action of rains. Besides, the meteoric effects upon any of the hills are small, compared with the encroachments of the waves, in exposing enough stones to make boulder pavements.

The occasional erratic blocks often reposing upon fine lacustrine deposits are of little importance, and indicate only an occasional stone entangled in old coast-ice from an adjacent shore, when the region was covered with water, just as the boulders resting upon the sunken ships in the mouth of the Baltic have been deposited from the coast-ice moving out of that sea.

The study of the relation of the pavements of boulders to beaches sets at rest the speculation upon the origin of these fringes, and obviates the necessity for appealing to either icebergs or glaciers in later Pleistocene days to account for the erratics, popularly called "hard heads," which are scattered over the country in the form of pavements or fringes; for these are usually seen only where they can now be referred to some old coast line, or a succession of shore lines, acted upon, in former days, by frost and coast-ice.

Chapter III.

High-Level Gravel Deposits in the Region of the Great Lakes.

Rather than rummage through the talus heaps of geological literature for the different kinds of gravel deposits which may represent beach structure, it is easier to go into the field of observation and investigate those forms which may be modified beaches, or be related to, or be mistaken for them. This method is the more satisfactory, as the geological literature often confounds different forms, and leaves others unnoticed, or not considered in the light of the present investigation. The object of this chapter is to describe

the various kinds of gravel deposits, which resemble or are related to beach structure, and not to consider their occasionally doubtful origin or distribution. Exclusive of the beds of sand, which are intimately connected with the stratified clays, or included in the drift accumulations themselves, and the ancient shores already described, the following groups of gravels and sands should be noticed, some of which are covered with the stony clay of the upper till:

I. *The gravels and sands which are buried beneath the upper drift deposits.* These may be divided into (*a*) buried beaches; and (*b*) more or less irregular beds and ridges of gravel and sand, often of earthy texture, having a more or less tumultuous structure, and resting beneath accumulations of the upper till.

II. *Surface accumulations of gravels and sands, forming ridges, mounds and plains.* These are in the form of (*a*) the so-called osars and kames; (*b*) other ridges and mounds resembling the last, but having a position corresponding to that of beaches, in front of more elevated plains or drift hills, or of the accumulations included in group I *b*; and (*c*) gravel plains.

I *a*.—Hitherto, the buried beaches have not been distinguished from other beds of gravel and sand intercalated within the drift formations. As such accumulations, whose structure is the same as that of modern beaches, are only exposed in sections cut through the surface deposits by streams or artificial excavations, all of the knowledge that we can, at present, hope to acquire, is the recognition that there were beaches, now covered by drift, older than those upon the surface of the country. When beds of gravel and sand are met with in borings, it is not always possible to distinguish those which are buried beaches from others which are intercalated with drift deposits. The structure of the buried beaches does not show that tumultuous crumpling, so commonly seen in the next kind of accumulations (I *b*). In some places the gravels are found cemented into conglomerates. Thin layers of stony clay, constituting the upper till, which covers vast areas of the country throughout the lake region, often rest conformably upon the undisturbed surfaces of the buried beaches, that may have a thickness of twenty feet or more. Excellent examples of buried beaches may be seen along the Au Sable river, near Lucan, Ontario, where the overlying drift clay is only four or six feet thick. When the covering is thin, there is sometimes a liability of mistaking these older beds for those belonging to the beach epoch proper.

I *b*.—The internal structure of this kind of gravel and sand deposits shows stratification, which may be regular in one place, but the beds soon become tumultuous, that is, the beds become irregular, bent or twisted, and confused. The materials are apt to be somewhat earthy. Throughout these layers there may occur occasional boulders of large size, and pockets of gravel,

whose outlines resemble those of boulders (as if the gravel had been cemented into masses by frost and then moulded into boulders, and afterwards deposited in the frozen state. By the characters just given, these accumulations can be readily distinguished from those of true beaches. They are commonly overlain by a few feet (perhaps ten or twenty) of stony clay or other materials of the upper till. Occasionally the covering may reach several times this thickness.

The external form of these deposits, with their clay mantle (which last is dependent upon the form of the underlying gravels), may be that of undulating plains, or these undulations rising to the magnitude of ridges and hills. In this case, the ridges rise in succession one above the other, until they reach an altitude of a hundred feet, or even more, above the plains which are commonly in front of them. They may occupy a breadth of several miles across the country. The ends of the ridges often overlap, and at other times send out spurs, and enclose kettle-like depressions, which are liable to be confounded with or not separated from those of the next group. These ridges form a considerable proportion of the so-called moraines of America. These slightly covered sand and gravel deposits are not so commonly developed below the altitude of 700 feet above the sea as at higher elevations, for the lower country is more apt to consist of terraces, cut in the drift, and of lacustrine deposits and beaches. But these accumulations cap the ridges of the great chain named the Oak hills, which extend for over a hundred miles in length, parallel to the northern side of Lake Ontario, at an elevation of from 900 to 1,200 feet above the sea. Farther west, such are also the capping materials of the country, which is 1700 feet above the sea. The same holds true for Michigan and other States.

II.—The gravels of this group are not only well water-worn but also well washed and free from earthy matter. Indeed, they are sometimes free from the finer sand. The pebbles are often coarser than in the lower beaches, in some cases forming accumulations of almost cobble stones. There are occasional boulders in the mass, but these are more common upon the surface. The materials are mostly of local origin, with a small proportion of transported crystalline stones. None of the materials have been derived directly from the subjacent Paleozoic rocks, but secondarily from the assortment of the stony boulder clays. The gravels with their accompanying beds of sand, when these are present, are stratified as in beaches, without anything of the tumultuous structure of the last group. Still, there may be false bedding, as in beaches; and when the deposits assume the form of ridges, the layers may dip in opposite directions, as in barrier beaches. The materials of this group are never covered with drift deposits, but often rest upon the till, or against hills of the tumultuous accumulations already described. In external form, the gravel deposits differ greatly, and it is upon this character that they are divided into the three series.

II *a*. *Osars* and *Kames*.—The osars (Anglicized from the Swedish word åsar, meaning gravel hills) being the term in America applied to very narrow gravel ridges (often only a few score yards in width at the base) or chains of mounds, winding in a more or less serpentine manner across a comparatively flat country, above which they rise at nearly as steep angles as the loose material will stand to a height of forty or sixty feet. They are also defined as generally extending from a higher to a lower country and following the course of the greater valleys—that is, at right angles to the coast lines. A beautiful example of an osar, as above described, is to be seen southeast of Lansing, Michigan. It trends into an inlet among the hills, oblique to the general direction of the ancient coast. Driving along the top of the ridge, which is scarcely wider than the road, it is seen to be composed of constantly and suddenly alternating stretches, each quite level, the one set being about twenty-five feet above the other. These so-called osars form a very limited proportion of the gravel ridges of this group.

The term kame (the Scotch vernacular for gravel hill), according to its use in America, is described by Chamberlin as "assemblages of conical hills and short irregular ridges of discordantly stratified gravel; between which are irregular depressions and symmetrical bowl-shaped hollows that give to the whole a peculiar, tumultuous, billowy aspect. . . . These irregular accumulations are, however, more abundant in connection with deep, rapidly descending valleys, being especially abundant where they are joined by tributaries or where they make a sharp turn in open portions of their valleys, and especially where they debouch into an open plainer country. In such instances they are usually associated with gravel terraces and plains. Precisely similar accumulations are very common associates, if not constituents, of terminal moraines. . . . They are transverse to the slope of the surface, the course of the valleys and the direction of the drift movement."* From observation in nature, as also from the description itself, it will be seen that the term kame is not specifically used, and that different kinds of gravel deposits are grouped under the same name. Indeed, from the above description, the term might be better applied to some of the deposits described above under group I *b*, which are more or less covered with clay. However, there are conical and tapering ridges in many localities without a tumultuous structure, whose relations to each other are not easily discernable, that may be placed here under the name of kame. Some of the kames in the valleys are doubtless river deposits, and others are the remains of uncovered buried beaches of greater age, exposed by subsequent erosion.

II *b*.—The internal structure of this series is similar to that of the other members of the group. The external form is that of intermittent ridges, sometimes rising to sixty feet above a frontal subaqueous coastal plain

* Third Annual Report of the U. S. Geological Survey, 1883, p. 300.

which is occupying the position as in front of a beach. The ridges may be replaced by cones, resembling delta deposits. The ridges are often scarcely less direct and scarcely more broken or more varying in height than beaches, especially when the subsequent erosion and unequal elevation, caused by terrestrial movements since the gravels were deposited, is taken into account. The ridges are often found to divide and enclose kettle-like depressions, sometimes dry and sometimes containing ponds or lakelets, just like similar depressions along modern beaches, but on a larger scale. Branches and spurs add to the undulating appearance of the country. In front of these hills the plains may be covered with gravel. It is very difficult not to see in these ridges the remains of beaches belonging to former shore-lines. A single ridge of this character occurs behind a plain just north of Stouffville, Ontario, rising to a height of seventy-five feet above the plain, which is about 1,100 feet above the sea. This deposit rests against another and somewhat larger ridge of sand and gravel belonging to group I *b*. Again, within a distance of about fourteen miles, stretching northwestward from a point near Flesherton (shown in fig. 7), there are three steps, each in the form of a slightly undulating plain, often paved with gravel, bounded by just such hills of gravel as are here described. These marginal ridges are much indented with kettle depressions (*k*, *k*, fig. 7), and are somewhat

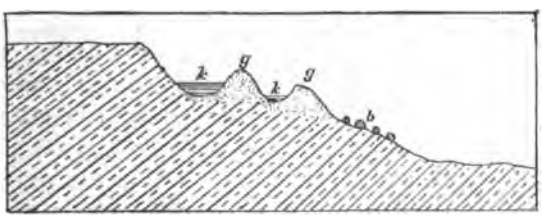


FIGURE 7—*Section extending Northward from near Flesherton.*

b = Boulder pavement. *g*, *g* = Ridges of Artemisia gravel. *k*, *k* = Depressions behind the gravel ridges.

beneath the level of well-marked terraces, as if a somewhat off-shore deposit. The elevation of the country above the sea descends from 1,600 to 1,200 feet. The ridges (*g*, *g*, fig. 7) border a mass of land that was rising out of, probably, the sea. The beach-like character of these accumulations is further brought out by the occurrence of zones of boulder pavements at levels below and immediately in front of the ridges (*b*, fig. 7). These boulder pavements, which do not enter the mass of the drift but only rest upon its surface, are too characteristic of the action of waves cutting into stony drift and of the accompanying action of coast-ice not to be regarded here as additional evidence of the coastal formation of the surface gravel ridges, described in this paragraph.

"Artemisia gravel" is a name applied by the Canadian Geological Survey to the gravels covering an area of 2,000 square miles of the highest land in Ontario, between the three lakes, Huron, Erie, and Ontario, rising in places to 1,700 feet above the sea. But the Canadian Survey did not recognize the different kinds of gravel accumulations. Indeed, its whole work upon the drift of Ontario was only pioneering, and now being somewhat antiquated and generalized, it is but a poor guide along a pathway enlightened by modern investigations. Thus the term Artemisia includes sand, gravel, and even upper till deposits (the last, although occupying thousands of miles of the surface of the Province, was not identified by the Survey) of all kinds and ages mentioned in this chapter and in that on beaches. However, it was the accumulation of the gravels described in this group II *b*, in the township of Artemisia, that gave the name which was extended over such a wide range of materials and geological time as if all were one formation. At most, the term should be restricted to the ridges occupying the position of very high-level beaches, just described.

II *c*.—Gravel plains are common in front of such high-level ridges as have been last described, representing the subaqueous floors when the waves beat upon the old shores. Some of them, however, may be the floors of terraces cut into the older gravel deposits. The plains are often very deeply eroded, owing to the high elevation of the country and the long action of meteoric agencies upon the incoherent materials. Thus, there sometimes remain of these plains only a succession of ridges, between ravines deeply excavated by the numerous streams and floods. Such plains occur in the typical region of the Artemisia gravel in Ontario, in Michigan, and in other States.

University of Georgia, August, 1889.

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ORIGIN OF THE ROCK PRESSURE OF NATURAL GAS IN THE TRENTON LIMESTONE OF OHIO AND INDIANA.

BY EDWARD ORTON.

(*Read before the Society December* 26, 1889.)

CONTENTS.

THE IMPORTANCE OF THE PRODUCT.

Natural gas derived from the Trenton limestone has supplied during the last year and is now supplying all the fuel and a considerable part of the artificial light that is used by at least four hundred thousand people in northwestern Ohio and in central Indiana. Within the same limits it is the basis of a varied line of manufactures, the annual product of which will make an aggregate of many millions of dollars. More than forty glass furnaces, not one of them three years old, are now in very successful operation within the territory named, while iron and steel mills, potteries and brick works, and a long list of factories in which cheap power is a desideratum, have been built up on all sides with wonderful rapidity.

The largest gas production of the Trenton limestone that has yet been reached is to be credited to the present year. A well drilled early last summer at Stuartsville, six miles north of Findlay, produced through the casing, a pipe 5⅝ inches in diameter, 28,000,000 cubic feet of gas every twenty-four hours. There are but few wells in any field that exceed these figures. Most of the wells so reported have been estimated, not measured.

An equally astonishing advance has been made in the oil production of this rock within four counties of northwestern Ohio. Single wells drilled during the last year have begun their production at a rate of 10,000 barrels

per day; and more than 200,000 barrels of total production are already to be credited to single wells of the new field, while a considerable number have passed the 100,000-barrel mark.

The Rock Pressure.

The rock pressure of the gas is a vital factor in all this production. To its energy is due the propulsion of the volatile fuel from the wells where it is released, through twenty, thirty, fifty miles of buried pipes, to the cities which it supplies with the unspeakable advantages of gaseous fuel. It is the same cause that lifts the oil from the rock in all flowing wells.

By rock pressure is meant the pressure which a gauge shows in a well that is locked in after the drill has reached the gas reservoir. The iron tubing of the well becomes by this means a part of the reservoir, and the same conditions as to pressure are supposed to pertain to it that are found in the porous rock below.

The rock pressure of gas varies greatly in different fields and to a less, but still an important, extent in different portions of the same field. The highest rock pressure recorded in the Trenton limestone is about 650 pounds to the square inch, while there are considerable sections of the gas territory that never reach 300 pounds pressure per square inch. The original pressure in the Findlay field was 450 pounds, varying somewhat in wells of different depths. In the Wood county field, from which the largest amount of gas is now being conveyed to Ohio cities, the original pressure ranged from 420 to 480 pounds, the general pressure being counted 460 pounds to the square inch. There were occasional records made of still higher pressure in single wells, but of such cases the number is very small, and the existence of these anomalous pressures was short-lived.

Passing to the westward, the gas wells of Auglaize and Mercer counties show a decided reduction in original rock pressure as compared with Findlay, though the depths of the wells remain the same as in that field. The highest pressure recorded in Mercer county is 390 pounds to the square inch, but no gauge was applied to the wells until they had been allowed to discharge without restraint for several months, while 375 and 350 pounds mark the extreme limit of other portions of this district.

In the Indiana field a still further reduction of rock pressure is to be noted. The range of the principal Indiana wells is between 250 and 325 pounds to the square inch. The Indiana gas wells, as compared with Ohio gas wells, are marked by a reduction in total depth, as well as in rock pressure, the figures for depth in the productive territory seldom or never passing one thousand feet.

How can these variations be accounted for? Back of this question is a larger one, viz: What is the origin of the rock pressure of natural gas?

THEORIES OF ORIGIN OF ROCK PRESSURE.

Considering its importance, the main question has received less consideration than would naturally be expected. The known literature of the subject is very meagre. Professor J. P. Lesley, in the Annual Report of the Pennsylvania Survey for 1885, discussed the question at greater length than any other geologist, so far as I know. In a paper published in the *American Manufacturer* May 27, 1887, I threw out a few suggestions as to the cause of rock pressure, and these suggestions I afterwards expanded into a more extended statement, in the sixth volume of the Geology of Ohio, page 96. Professor I. C. White reminds me that he suggested an explanation in the journal named above at an earlier date than either of those given.

The men who are engaged in the practical development of gas and oil fields make great account of rock pressure. It is the first fact that they inquire after in a new gas field. They appreciate its importance in whatever utilization of the gas they may propose, knowing that the distance of the markets that they can reach and the size of the pipes that they can employ are entirely dependent upon this element. These practical men, so called, are, as is well known, among the most venturesome of theorists, and a question like this would not be likely to be left unanswered by them. A certain rough correspondence that exists between the depth and the rock pressure of wells is made of great account in explanations that they offer. In other words, the pressure is supposed to be due to the weight of the overlying rocks; and next to this we find among them the expansive force of gas the favorite explanation of the phenomenon.

In the paper of Professor Lesley, already referred to, the learned author suggests the two possible explanations of rock pressure already named, and to this he adds a third, viz., hydraulic pressure; but he adds this explanation only to reject it as a true cause of the phenomenon under discussion. The absurdity of the more commonly received explanation of rock pressure, as due to the depth of the well—in other words to the weight of the overlying country,—he sets in such clear light in his discussion that no further consideration of this is required on the part of those who are open to reason. Until we can prove, or at least render it probable, that the gas rocks have lost their cohesion and that they exist at the depths of storage in a crushed or comminuted state, no explanation can be based upon the weight of the overlying rock in accounting for the force with which the gas escapes from its reservoirs when they are penetrated by the drill. Professor Lesley throws the whole weight of his authority in favor of the view that the gas "produces its own pressure, like gas generated by chemical reaction in a closed vessel." This explanation certainly leaves something to be desired, for it fails to account for the most significant and important facts in this connection, viz., the differences of rock pressure in different localities and at different depths.

To accept it brings us no advantage whatever beyond the satisfaction that we may feel in having an answer at hand that can be promptly given to a troublesome inquiry.

For my own part, I have felt certain for more than two years that the rock pressure of gas in the Trenton limestone of Ohio and Indiana is hydrostatic in origin, and I have published a number of facts that seem to me to give support to this view. I find that some sagacious operators in the new gas and oil fields are coming to the same ground. They have become thoroughly satisfied by their own experiences that the cause of rock pressure is to be found in the water column that stands connected with the porous rock in which the gas and oil are contained. In the present paper, I desire to present to the Geological Society a few facts and conclusions bearing upon the subject.

THE DATA FOR THE HYDROSTATIC THEORY

The first question is, What are the facts as to the rock pressures of the gas rock in question, and what relations do they bear to the depth of wells and other conditions in the Trenton limestone? The answer is not as full and definite as may be expected, certainly not as may be desired. There is but one time in the development of a gas field in which the normal gas pressure can be ascertained, and that is when the first well reaches the reservoir and releases the long-imprisoned and greatly compressed gas. But often this favorable opportunity is lost, and gauges are not applied to wells until the energy of the first flow is somewhat abated. Again, different wells in the same field, as Findlay for example, give different results. The wells vary with the depth at which the gas rock is found. This factor is found to be an essential one, as will presently be shown, in connection with rock pressure. Moreover, gauges are sometimes inaccurate, and their errors come in to confuse the study of the subject. Furthermore, the exact depth of the wells and the exact altitude of the surface where they are located cannot be ascertained in all cases. Small errors of this sort must be provided for, and there also enters into the discussion a question as to the specific gravity of the water which is to be made the moving force of gas and oil. The water found in association with these substances is never fresh. It is always saline, and often highly mineralized. The weight of fresh water to the square inch is 0.4328 pound for one foot in height (I use Professor Lesley's tables). The average weight of sea water is 0.445 pound to the square inch for one foot, but the mineral waters with which we find the Trenton limestone saturated often reach a much higher figure. An examination of several specimens shows that a column one foot high would weigh to the square inch 0.475 pound. In fact, some of these waters are more like bitterns, and their columns would equal or exceed 0.5 pound per foot.

Bearing these several sources of ambiguity or uncertainty in mind, we can consider the records of pressure, depth, and the other factors that are accessible. The figures as to pressure have already been summarized in a preceding paragraph, but they will be repeated in an accompanying tabular statement. Before coming to this, however, let me in the briefest terms review the conditions under which gas, oil, and salt water exist in the Trenton limestone. The uppermost beds of the great Trenton formation in northwestern Ohio, central and northern Indiana, Michigan, Illinois, and Wisconsin consist of a porous dolomite, five, fifty, one hundred, or even one hundred and fifty feet in thickness. Sometimes the dolomite is found in a continuous body, but oftener in interrupted beds. This part of the formation has outcrops in the Manitoulin islands of Lake Superior, and in the Galena limestone of Illinois and Wisconsin. In the gas and oil fields, it is found lying in terraces and monoclines, or flat arches, eight hundred to fifteen hundred feet below the surface; and these several features effect the separation of the varied contents of the porous rock. The boundaries of gas, oil, and salt water are easily determinable and are scrupulously maintained in the rock, except that as soon as development begins the salt water is always the aggressive and advancing element. When the drill descends into the gas rock proper, dry gas escapes; when into the contiguous and lower-lying terrace, oil accompanied with gas appears, as already described; but at a little lower level salt water is struck, and this rises promptly in the well, sometimes to the point of overflow. Far out from the narrow ridges or restricted terraces where gas and oil are found the salt water reigns undisturbed, and wherever reached by the drill it rises in the wells as in those already described. It would be in the highest degree absurd to count the little pockets of gas that are found in the arches the cause of the ascent of this ocean of salt water a score or a hundred miles away. The rise of the salt water is unmistakably artesian. It depends on hydrostatic pressure, as does the flow of all artesian wells, and its head must be sought, as in other like flows, in the higher portions of the stratum that are contiguous.

The nearest outcrops of this porous Trenton have been already named. They are found in the shores of Lake Superior at an altitude of about six hundred feet above tide. It is certainly significant that when an abundant flow of salt water is struck in a boring in northern Ohio or in Indiana, no matter at what depth, it rises generally about to the level of Lake Superior; or, in other words, about six hundred feet above tide. If the mouth of the well is below this level, as is the case in the Wabash valley, the salt water overflows. On the shore of Lake Erie the water rises to within 20 feet of the surface; in Findlay, to within 200 feet. The height to which the salt water rises in any portion of the field is one of the elements to be used in

measuring the force which can be exerted on the gas and oil that are caught in the traps of the terraces and arches of the porous Trenton limestone.

Why, then, is not the rock pressure of the gas the same in all portions of the new horizon? For the obvious reason, I reply, that there is a varying element involved, viz., *the depth of the rock below sea level.* The surface elevations at the wells vary greatly, and the wells of the same depth consequently find the gas rock in very different relations to sea level.

The Test of the Hydrostatic Theory.

It is obvious that if an explanation of the rock pressure of the Trenton limestone gas is attempted on this basis, there are facts enough now at command to substantiate or overthrow it. By the facts it must stand or fall. In the accompanying table I have indicated the following lines of facts as to strictly representative wells in the leading districts of the new gas fields, viz: (1) location, (2) depth at which gas is found, (3) relation of this depth to sea level, (4) the initial rock pressure of the gas. In regard to the last line of facts I have taken, in almost all cases, figures that I have myself verified. (5) A fifth column I add, in which the pressure due in the particular well is calculated from the two following elements, viz., an assumed elevation of the salt water to the Lake Superior level, or six hundred feet above tide; and, secondly, an assummed specific gravity of the salt water of the Trenton of 1.1, which gives a weight of 0.476 pound to the foot.

Locations.	Depth to Gas.	Relation of Gas Rock to Sea Level.	Original or first Observed Pressure.	Calculated Pressure. 1′=0.476 lb.
Ohio.				
Tiffin, Loomis & Nyman Well,	1500 ft.	747 ft. below tide.	650 ? lbs.	641 lbs.
Upper Sandusky, Well No. 1,	1280 "	478 " "	515 "	513 "
Bloom Tp., Wood Co., Godsend Well,	1145 "	395 " "	465 "	473.6 "
Findlay, Pioneer Well,	1120 "	336 " "	450 "	445.7 "
St. Mary's, Axe Well,	1159 "	238 " "	390 "	398.8 "
St. Henry's, Dwyer Well, No. 1,	1156 "	200 " "	375 "	385 "
Indiana.				
Kokomo, Well No. 4,	936 "	98 " "	320 "	332 "
Marion, Well No. 3,	870 "	78 " "	323 "	322.7 "
Muncie	900 ? "	At tide level.	300 ? "	286.6 "

These figures seem to me to settle the question as to the origin of the rock pressure of the gas in this formation. I feel sure that nicer determinations of the facts involved as to altitude and depth would bring a still closer agreement between columns four and five. I will ask you to note in particular the facts as to the St. Mary's and the St. Henry's wells. They have practically the same depth, 1159 and 1156 feet; but there is a difference of thirty-eight feet in the depth of the gas rock with reference to sea level. There is a corresponding difference in the rock pressure of fifteen pounds, as recorded. The difference in rock pressure due to this thirty-eight feet by calculation is 13.8 pounds, or practically fifteen pounds. I presume that column five is as near the truth in this particular as column four. The gauge would quite certainly be reported 385 pounds if it lacked but one or two pounds of that number.

The Laws of Gas Production.

The laws of gas and oil production and accumulation are coming to light more clearly in the flat country of Ohio and Indiana than they have ever done among the hills and valleys of the older Alleghany fields. As it seems to me, no more important deduction from the new districts has been reached than the law now stated, viz., *The rock pressure of Trenton limestone gas is due to a salt-water column, measured from about six hundred feet above tide to the level of the stratum which yields the gas.* The column can be conveniently counted as made up of two parts, viz., a fixed length of six hundred feet added to the depth of the gas rock below tide.

If this explanation is accepted as satisfactory for Trenton limestone gas, I venture to suggest that the fact will go a great ways toward rendering probable a like explanation for rock pressure in all other gas fields; but I will not at the present time venture to extend it beyond the limits I have named. I am aware of certain facts, or at least supposed facts, from the older fields that seem difficult of explanation on this basis.

There are a few obvious inferences from this law to which I venture to call your attention in closing this paper:

1. There is no danger that the great gas reservoirs of to-day will "cave in" or "blow up" after the gas is withdrawn from them. The gas will not leave the porous rock until the salt water obliges it to leave by driving it out and taking its place.

2. This doctrine lays the ax at the root of all the optimistic theories which blossom out in every district where natural gas is discovered, and especially among the real-estate operators of each new field, to the effect that Nature will not fail to perpetually maintain or perpetually renew the supplies which

we find so delightfully adapted to our comfort and service. So far as we are concerned, it is certain that Nature has done about all that she is going to do in this line. In her great laboratory, a thousand years are as a single day.

3. No doctrine could exert a more healthful influence on the communities that are enjoying the inestimable advantages of the new fuel than this. If it were at once accepted, it would add years to the duration of these precious supplies of power. The ignorant and reckless waste that is going on in the new gas fields is lamentable. The worst of it comes from city and village corporations that are bringing the gas within their boundaries to give away to manufacturers whom they can induce on these terms to locate among them. To characterize the use of a million feet of natural gas a day, in a single town, for burning common brick, for example, or in calcining common limestone, there is a good word at hand, viz., *vandalism.*

4. If this doctrine of the rock pressure of gas is the true one, the geologists who have to deal with the subject and the communities that have found a supply owe it to themselves to keep it prominently before the people, who are especially interested. They may make themselves temporarily disagreeable thereby, but by just so far as they convince those that are interested, they lengthen the life of these precious supplies.

The Duration of Gas Supply.

Judging from the present indications, the Trenton limestone gas of Ohio is not likely to be long-lived. It seems entirely probable that the term of its further duration can be stated within the limits of numbers that are expressed by a single digit. In considerable sections of the field, the salt water is very aggressive. It requires a steadily increasing pressure on the wells to hold it back. In one district last year, one hundred and twenty-five pounds pressure would keep the gas dry, while now two hundred pounds are required for the same purpose.

There is likely to be great disappointment in regard to what is called gas territory. The pressure and volume of large areas are found to fail *together.* Wells draw their supplies from long distances. A farm, or even a mile-square section, may be effectually drained of its gas without a well being drilled upon it.

Natural gas is a very admirable product, but its highest office, after all, should be to prepare the way for something better than itself, viz., artificial gaseous fuel—better, for the reason that while it furnishes all the intrinsic advantages of natural gas, it will be free from the inevitable disadvantages of treasures secured in the way in which the stores of the great gas fields have been gained.

DISCUSSION.

Professor I. C. WHITE: I can add but little to the admirable presentation by Professor Orton. My studies in the Pittsburgh region have long ago confirmed the absolute proof which Professor Orton has just given us. I stated as early as 1886, in an article on this subject, that in my view it was due to artesian pressure. This idea was also adopted by Mr. Westinghouse, president of the largest gas company in the world, the one which supplies Pittsburgh with natural gas. But singularly enough, although president of this great organization, and having this idea in his mind in regard to the origin of the pressure of gas, his company made no attempt to shut in any wells until 1887, simply because the superintendents were afraid that the pressure developed when the wells were closed would blow up the casing. Finally, when the subject of the great waste of natural gas was agitated in the papers and in the legislature, the superintendent of the field operations undertook to shut in a well. He piled around a derrick several tons of stone, cemented it together, and prepared for a pressure of something like two or three thousand pounds to the square inch. To his great surprise, the pressure gradually went up to only 500 pounds. After that they very soon shut in every well they had.

Now, although the rock that produces the gas in that region is a sand instead of dolomitic limestone, as in Ohio, yet there is no reason to doubt that it would show the same results Professor Orton has demonstrated. All the data that I have collected goes to prove this statement. There is an increase of pressure with the depth of the wells. The largest pressure that I know of is 1,000 pounds to the square inch. This is in the valley of the Ohio near Pittsburgh, and it took the well several hours to attain that pressure; the depth was about 2,200 feet, and when proper calculations are made from the point where that rock emerges from the Conemaugh river, the pressure is sufficiently accounted for on artesian principles. The wells in the Murraysville district are surrounded by what is called soda water, which has the character of a bittern. It is not very salt, and some people drink it as a mineral water; but its specific gravity is very high. The first well struck in Murraysville was allowed to play into the air for six years, discharging 20,000,000 feet of gas daily, before any attempt was made to utilize it; so that the original pressure of that field was probably never obtained. The most reliable estimate ever made places it between 600 and 700 pounds to the square inch, which would be about what it should be according to these calculations of artesian pressure.

The largest well I have ever known in the Pittsburgh region is one that developed a pressure of 800 pounds in a minute. That well was sold for $100,000. This will give you some idea of the value of the gas, which, as

Professor Orton says, a practical man estimates according to the pressure it will attain in a minute. In the region contiguous to Alleghany county and Washington they have about five producing horizons. They are all porous sand rocks, and there is an increase in pressure with the depth such as represented by Professor Orton's figures; so that, where it is possible to get any data with reference to these wells, they seem to amply confirm his statements.

Dr. A. C. LAWSON: I understand that Professor Orton has suggested the possible connection between the pressure of 600 feet of salt water and the level of Lake Superior. I would ask whether that figure represents a horizontal plane in the earth's crust, or whether it has a slope from 600 feet down to zero?

Professor ORTON: So far as my observation goes, in Michigan, Indiana and Ohio, the surface of the salt water is a horizontal plane. The water does not always rise promptly, but give it time and it rises to the level already named. For example, a deep well has lately been drilled in Erie, Pennsylvania, and salt water, apparently derived from the Trenton limestone, has risen from a depth of about 3,000 feet to the lake level.

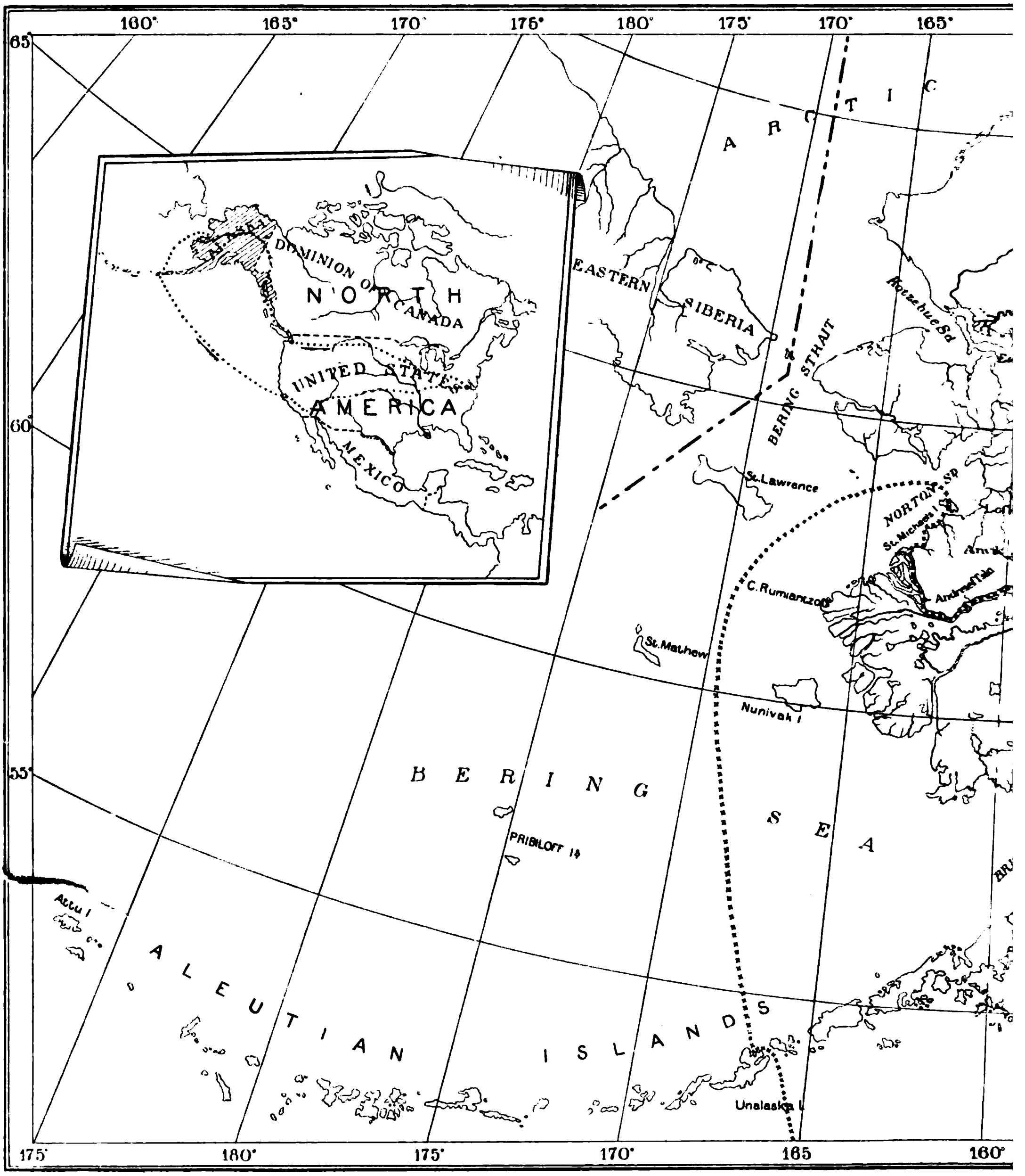
Dr. LAWSON: I would like to ask the extent to which capillary attraction in the rocks raises salt water in the column above the sea level?

Professor ORTON: I would not presume to answer that, but this factor is taken out of the account, from the presence of the impervious shale that makes in all cases the cover of the gas rock or oil rock and that prevents the ascent of the salt water; and it is the penetration of this cover that gives us our first access to the gas, oil, and water that are contained in these porous rocks.

Mr. W J McGEE: A few months ago I had occasion to make a study of the Indiana gas field. Fortunately I was acquainted with Professor Orton's work in Ohio, and not only made use of the theory which he has so well developed, but was able to fortify it by a large number of observations (made chiefly by a collaborator of the U. S. Geological Survey, Dr. A. J. Phinney) in my hands at that time; so I can supplement Professor White's remarks by saying that this theory explains in a satisfactory manner the phenomena displayed by all the gas fields of Indiana—those of the great central field and those of most of the smaller outlying fields as well.

I desire to add a more general tribute to the excellent work recorded in Professor Orton's communication. In my judgment, the most important advance ever made in economically applied geology in a brief period was that made within the last three years in the United States. Three years ago rock gas with all its phenomena was a mystery to the geologist as well as to the layman, and the geologist was as completely in the dark as the prospector concerning the origin of the gas, concerning the laws of its distribution, concerning the cause of the rock pressure, and concerning other important ques-

tions connected with it. But within the past three years the laws governing the origin, distribution, and pressure of rock gas have become as well known as are the laws governing artesian water supply; so that to-day the geologist prognosticates rock gas nearly if not quite as definitely and certainly as he prognosticates artesian water; and it is only just to our associates and to American science to say that this great advance in geologic science was due almost wholly to two of our fellows—to Professor Orton, the author of the communication before us, and to Professor White, who has already spoken upon it. To these two men we are indebted for this unparalleled stride in American geology. Others, indeed, contributed facts, but they philosophy; and science was immeasurably enriched by their contribution.



SKETCH MAP
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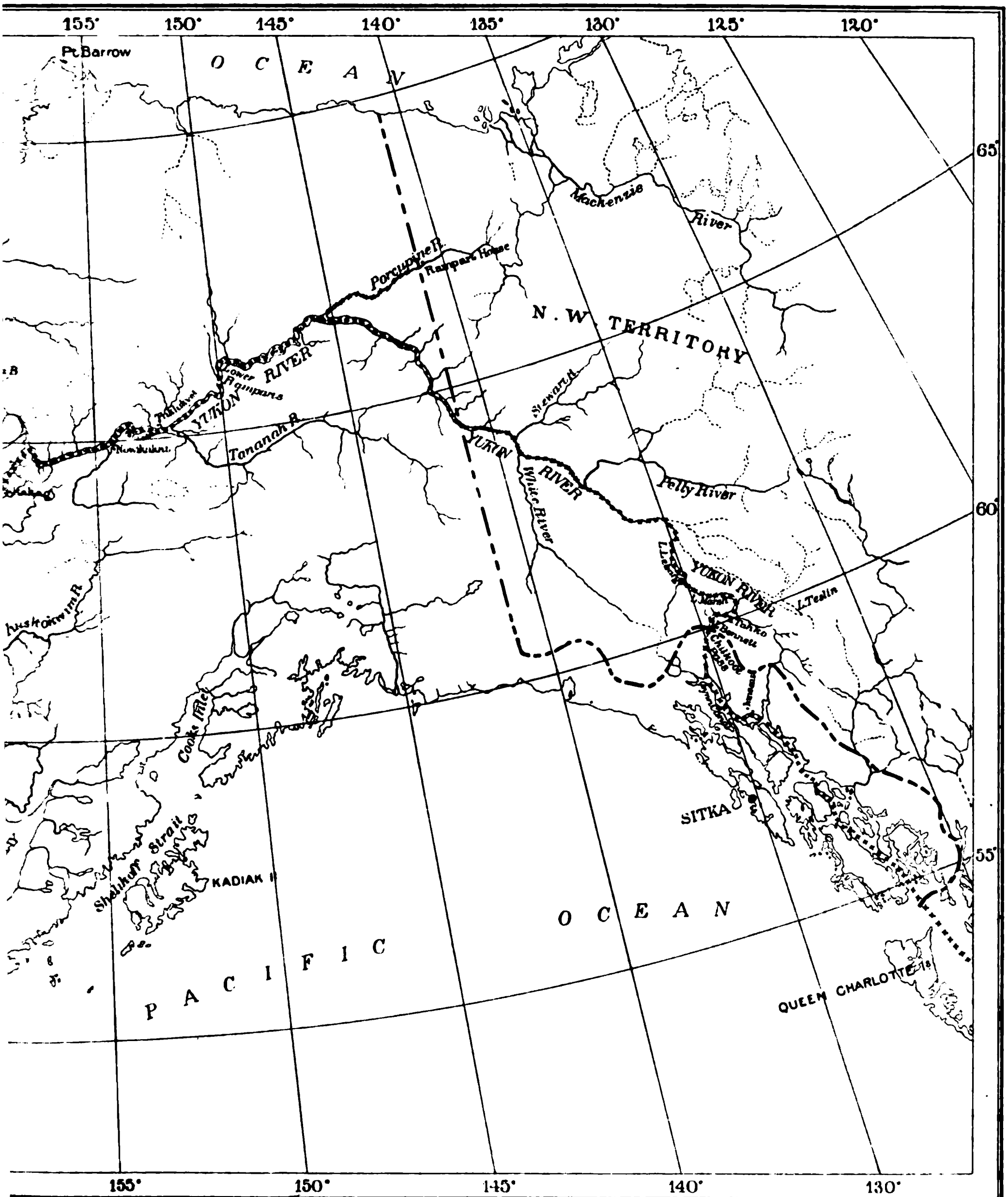

H. S. Hen, Draftsman.

)F ALASKA

RUSSELL IN 1889 ....

97 miles : 1 inch

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NOTES ON THE SURFACE GEOLOGY OF ALASKA

BY ISRAEL C. RUSSELL

(*Read before the Society, December* 26, 1889)

CONTENTS

INTRODUCTION.

In the spring of 1889, the U. S. Coast and Geodetic Survey organized and equipped two parties in San Francisco, Cal., for the purpose of establishing the position of the boundary between Alaska and the North West Territory of Canada. These parties were in charge of J. E. McGrath and J. H. Turner, officers of that survey, and had for their destination localities on the Yukon and Porcupine rivers respectively, where those streams cross the 141st meridian.

Through the courtesy of the Superintendent of the U. S. Coast and Geodetic Survey, the Director of the U. S. Geological Survey was invited to send a representative with the boundary survey parties for the purpose of making geological observations in Alaska. This duty was assigned to me, and a record of such observations as the character of the journey undertaken enabled me to make is presented in the following pages.

The expedition sailed from San Francisco on the steamship "Bertha" June 14, 1889, and reached Iliuliuk, Unalaska island, June 27. We remained at Iliuliuk four days; our effects having then been transferred to the steamship "St. Paul", we sailed for St. Michaels June 30, and, crossing Behring* sea, reached there July 7. We remained there until July 14, when, all arrangements for ascending the Yukon having been completed, the final stage in our journey was begun. The ascent of the river was made in the stern-wheeled steamboat "Yukon", belonging to the Alaska Commercial Company and built especially for the navigation of the rivers of Alaska.

Our voyage up the Yukon was slow but did not allow much time on shore. No stops were made except to obtain wood or provisions until arriving at Fort Yukon, and such brief opportunities as were available for land excursions were frequently at localities where geological exposures were poor.

We reached the site of Fort Yukon on August 2, and there landed Mr.

*Spelled in four ways: "Bering," "Beering," "Behring," and "Bhering." The third form has the authority of the gazetteers, but the first is preferable and appears in the accompanying map, pl. 2.

McGrath and his party for the purpose of making astronomical and magnetic observations, while the steamboat proceeded up the Porcupine river with Mr. Turner and his party. I accompanied Mr. Turner to within about forty miles of his destination; which was as far as the steamboat could go, owing to low water in the river. On returning from the Porcupine river trip I remained a few days at Fort Yukon, and then proceeded to Mr. McGrath's station on the Yukon at the boundary, arriving there on August 19. I remained with Mr. McGrath about a week, and then continued the ascent of the Yukon, reaching the mouth of the Pelly river, the destination of the "Yukon", on August 31.

On arriving at Pelly river I made arrangements for continuing my journey with a party of miners who were on their way from Forty-mile creek to Juneau. We left the site of Fort Selkirk on September 1, and "poled" and "tracked" our open boat up the Yukon to the mouth of the Lewes, and then ascended that stream, passing through lakes Lebarge, Tagish, Nares, and Bennett to Lake Lindeman. From Lake Lindeman, which is at the head of boat navigation, I crossed the Chilkoot pass on foot, and reached the head of Taiya inlet, the extreme northern reach of Lynn canal, on October 1. From there I proceeded to Juneau in an open boat, and took passage in the steamship "G. W. Elder" for Port Townsend, and thence proceeded to Washington, D. C., by rail.

The time spent in Alaska and the neighboring portion of the North West Territory, during which at least occasional opportunities for geological work were afforded, was about three months. During that time I traveled by steamboat, open boats, and on foot about twenty five hundred miles. Opportunities for geological work were thus necessarily very limited.

The accompanying paper has been prepared not with the hope of contributing largely to geological science, but because the observations relate to a little-known region and for that reason may have some interest. If the paper serves no other purpose than to direct the attention of future travelers to certain questions of geological importance, I shall consider that it has not been written in vain.

The route followed had been previously traversed by W. H. Dall from St. Michaels to Fort Yukon, and by G. M. Dawson from the mouth of the Pelly river to Juneau. Since returning I have learned that previous to my journey R. S. McConnell descended the Porcupine river to its mouth, and then followed the same route to Juneau that was traversed by Dawson and myself. An account of McConnell's explorations was read before the American Geological Society at its New York meeting, in December, 1889, and appears elsewhere in this volume. In the following pages references will frequently be made to the writings of the gentlemen just mentioned, and I am pleased to say these will necessarily be in the direction of commendation.

In order that these observations may be easy of reference they are arranged under definite heads, as shown in the accompanying table of contents. All references to the personal incidents of the journey have been omitted for the reason that the trip was in no way an original exploration, so far as a general knowledge of the region visited is concerned. In following this course I may be doing an injustice to my companions and fellow-travelers, to whom I am indebted in many ways, and especially to Messrs. McGrath and Turner, who did all in their power to make the trip both pleasant and profitable. While writing these pages my thoughts often revert to the lonely snow-bound cabins in the far North, where my friends and comrades of many weeks of interesting travel are keeping their vigils with the stars.

I am also indebted to the Alaska Commercial Company for allowing me to accompany the expedition free of expense.

My companions in the arduous journey from Fort Selkirk to the head of Lynn canal were Frederick Miller, Frank Cromier, Henry Lariviere, and Joseph Beauchreau—all open-hearted frontiersmen of wide and varied experience, to whom I am indebted not only for personal assistance but for much valuable information.

In closing I wish to call attention to two enterprises which might greatly assist the development of the interior of Alaska.

The *first* is a survey of the Yukon delta, which would determine whether there is a channel by which ocean-going vessels can enter the river.

The *second* is a survey of the passes between the head-waters of the Yukon and the coast. This would furnish those interested in the development of the country the needful data for making trails and wagon roads from the sea-shore to the head-waters of the great river system of the interior. There are four passes more or less practicable for this purpose, none of which have been surveyed. Beginning with the easternmost, the *first* is the Taku pass. It lies between the head of Taku inlet, just east of Juneau, and the head of A-tlin lake, or the head of the Tako arm of Tagish lake. This is reported to be a very low divide, too low in fact to be called a pass, and is thought to be practicable for a wagon road. The *second* is White pass, leading from Taiya inlet, at the head of Lynn canal, to the Tako arm of Tagish lake. The *third* is the Chilkoot pass, already well known in a general way. The *fourth* is the Chilkat pass, leading from the Chilkat inlet, at the head of Lynn canal, to the head of the Tahk-heena river, which joins the Lewes a few miles above Lake Lebarge.

So far as I can judge, the most practicable of these several routes, though not the shortest, is the Taku pass. While there is reason to suppose that a wagon road could be constructed on this route without great expense, there is little doubt that the other routes mentioned are entirely impracticable for the purpose. The White and Chilkoot passes are considered available for

pack-train trails, and afford the most direct lines of communication between the navigable waters of the coast and the lakes and rivers of the interior.

The interior of Alaska is known to be of value on account of its deposits of gold, copper, and coal, its fisheries and its furs. It is claimed also by many who are familiar with the region that it will ultimately be settled by an agricultural people who are inured to the rigors of an arctic climate. It seems, therefore, that the most practicable routes to the interior should be made known at an early date, not only with the view of reducing the cost of transportation, but also of decreasing the hardships and dangers attending the crossing of the passes in their present condition.

Nomenclature of the Yukon River and its Tributaries.

In writing about the Yukon river and its tributaries, an unfortunate confusion in nomenclature is met at the outset.

The early exploration of the Yukon by Europeans was made in part by Russians, who came from the west and ascended it from the sea; and in part by members of the Hudson Bay Company, who came from the east and explored and named some of the principal streams forming its head-waters. When the connection of these various fragmentary explorations was established, a confusion of names resulted.

Later travelers visiting the same region not only ignored the aboriginal names as did their predecessors, but also refused in certain instances to recognize well-established English and Russian names.

The history of discovery in central Alaska and the adjacent part of the North West Territory has been recorded by W. H. Dall in his great work, "Alaska and its Resources", and has recently been judiciously discussed by G. M. Dawson.* The thorough manner in which these writers have performed their tasks renders it unnecessary to discuss here the origin of the various names proposed for the river of Alaska. It does appear desirable, however, to determine what names shall be used in this paper for the streams traversed, and especially to decide to what stream the name "Yukon" shall be applied. Referring the reader to the writings of Dall and Dawson for a history of the nomenclature of the great river of Alaska and its tributaries, attention may be called to two authoritative examples of the present use of the name Yukon.

The last edition of the general map of Alaska published by the U. S. Coast and Geodetic Survey may be considered as a leading authority on the nomenclature as well as on the positions of Alaskan rivers, since it embodies the results of all explorations available at the time of its publication.

* Report on an exploration in the Yukon district, N. W. T., and adjacent northern portion of British Columbia, 1887; in Geological and Natural History Survey of Canada, Annual Report (new series), Vol. 3, Part 1, 1887-'88; Montreal, 1889. Part B, pp. 14B-18B, 154B-156B.

On the map referred to, the name Yukon is applied to the stream which flows from Lake Lindeman—or, more precisely, from Crater lake, since Lieutenant Schwatka's nomenclature for the river is followed—and after passing through lakes Bennett, Tahko, Marsh, and Lebarge, is joined by the Pelly, Stewart, and Porcupine rivers. From the junction with the Porcupine to the sea there is, I believe, at present no duplication of names, the word Yukon being in current use by all writers on the subject.

Dawson has shown, in his report already referred to, that the extension of the name Yukon so as to include the stream flowing from Crater lake does violence to the nomenclature proposed by early explorers, and, moreover, does not conform to the geography of the region. As stated by Dawson, and as I have learned also from other sources, Crater lake is not the main source of the Yukon, but of one of its secondary branches.

In Dawson's report and on the maps accompanying it, choice among the names proposed by various explorers has been controlled by precedence. What is known as the Yukon on the U. S. Coast and Geodetic Survey map referred to above is divided into three portions: From the sea to the mouth of the Porcupine river the name Yukon is retained; from the mouth of the Porcupine to the mouth of the Upper Pelly it is called the "Pelly"; thence to Tagish lake it is the "Lewes." The main source of the Lewes is considered to be the stream which enters the Tahko arm of Tagish lake, while the stream from Crater lake, flowing through Lake Lindeman, is a secondary branch.

As the streams concerning which there is a duplication of names are chiefly in Canadian territory, I was strongly inclined to follow the usage of Canadian geologists and explorers; but in attempting to do so, the inconvenience of their system, as well as its disregard of geographical conditions, forced me to reject it.

In topographic nomenclature account should doubtlessly be taken of the names proposed by early explorers. The exclusive use of this system, however, not only tends to confusion, but often entails an unnecessary burden on writers and students of geography. The exploration of the Yukon drainage system is yet far from complete, and we still have it in our power to so adjust the names applied to it as to make them conform to geographical conditions and yet not do geat injustice to the work of early explorers.

To one ascending the Yukon from the sea it is evident that no change of name should logically occur where the main stream is joined by the Porcupine, as there is no perceptible change in its character at that locality. The same is true when the mouths of Stewart river and Pelly river are reached. Continuing to ascend the main stream above the mouth of the Pelly, one arrives, after voyaging about 150 miles, at the mouth of the "Tes-lin-too," as it is named on many maps.* This stream, in my judgment, is in reality

* This is the "Hootalinkwa" of miners, and the "Newberry river" of Schwatka.

the continuation of the Yukon and should share its name. It flows through a continuation of the same orographic valley that is occupied by the Yukon (or "Lewes") below its mouth, while the Yukon (of the U. S. Coast Survey map) or the Lewes (of Dawson's map) above the junction is but a tributary stream, coursing through a narrow and poorly defined valley nearly at right angles to the main line of drainage.

The fact that the so-called Tes-lin-too occupies a continuation of the Yukon (Lewes) valley proper has been clearly recognized by Dawson, as is shown by the following quotation:

"The valley near the mouth of the Tes-lin-too is again narrower than usual, singularly so for the point of confluence of two important rivers. The valley of the Tes-lin-too is evidently the main orographic depression which continues that occupied by the Lewes below the confluence. The Lewes flows in through a narrow gap, closely bordered by high hills and nearly at right angles to the lower course of the river. On the map accompanying Lieut. Schwatka's report, the width of the Tes-lin-too is shown as about half that of the Lewes, the actual fact being precisely the reverse and all the main features of the lower river being contained by the Tes-lin-too; while the other branch, both in its irregular mode of entry, the nature of its banks, the color of its water and its very rapid current, presents, at first sight, all the appearance of a tributary stream of new character. To such an extent is this difference observable, that Mr. Ogilvie and the members of his party, as well as most of the miners on the river, were of the opinion that the Tes-lin-too actually carries much the greater volume of water. As this appeared to be a question of some importance, we stopped a day at the confluence for the purpose of investigating it, cross-sectioning each river and ascertaining the rate of the current at distances of about half a mile from the junction, where the circumstances were favorable. It was thus ascertained that the rivers possess the following dimensions:—

	Lewes.	*Tes-lin-too.*
Mean width	420 feet.	575 feet.
Maximum depth (near left bank)	12 " (near right bank)	18 feet 4 in.
Sectional area	3,015 "	3,809 feet.
Maximum velocity	5.68 miles pr. hr.	2.88 miles pr. hr.
Discharge per second	18,664 cubic feet.	11,436 cubic feet.

"In connection with these measurements it may be stated that the Lewes showed evidence of having risen about a foot above its lowest summer level, while the Tes-lin-too was probably near its lowest summer stage. (All the rivers in this country reach their actual minimum toward the end of the winter.) If we subtract the volume of water represented by this extra foot in depth, the discharge of the Lewes at the summer low-water stage may be approximately stated at 15,600 cubic feet."*

The secondary character of the stream draining Lake Lebarge where it joins the "Tes-lin-too" is indicated by the fact that a party of miners who had descended from Lake Lindeman to Forty-mile creek, and might there-

* Rep. Yukon District, loc. cit., p. 153B.

fore be supposed to have some idea of the drainage system, in attempting to return, passed its mouth and ascended the main stream for over fifty miles before discovering their mistake. My observations while at the junction of the rivers just referred to confirm what Dawson has written concerning that locality. It seems evident to me that no unprejudiced observer could examine the junction without concluding that the "Tes-lin-too" should be regarded the main drainage channel.

In this paper the nomenclature adopted by Dawson will be followed so far as it accords with the geographical conditions. The name Yukon will be applied to the main trunk of the drainage system now under discussion from its mouth to its source, the source being in the as yet unexplored region draining into Lake Teslin. The name Lewes will be retained for the stream on which Lake Lebarge and the numerous lakes higher up in the same system are situated. The main source of this stream, as stated by Dawson, is unquestionably to the southeast of the Tako arm of Tagish lake, but like the source of the Yukon it awaits exploration. A branch of the Lewes has its source in Crater lake and is the route now usually followed by persons entering the Yukon region from Juneau.

When the lake region drained by the Lewes is fully explored, and especially when it becomes popular among summer tourists—an event perhaps not very remote—the separate reaches of the river connecting the various lakes will for convenience probably receive individual names.

Before dismissing this subject, attention may be called to the fact that Dawson, who is the only authority on the geography and geology of the Yukon district of the North West Territory, regards the main source of the Yukon to be the Lewes. The reasons for this conclusion are stated in part in the quotation given on page 106, and in part in other portions of his report. On page 16 B he says: "Whether reckoned by size or distance from its mouth, the source of the Lewes must be placed at the head-waters of the Hotilinqu river;" and in a foot-note on the same page: "The Tes-lin-too occupies the main orographic valley above its confluence with the Lewes, but is smaller than the Lewes, and besides doubles back on its course, as is shown on the map."

The measurements made by Dawson place the discharge of the Lewes at 15,600, and of the "Tes-lin-too" at 11,436 cubic feet per second. Volume, so far as shown by this single measurement, is in favor of the Lewes. This circumstance is more than counterbalanced, however, in my opinion, by the character of the channels or valleys of the streams in question. The main orographic valley is occupied by the "Tes-lin-too," and there is no noteworthy change in its configuration where it receives the stream flowing from Lake Lebarge.

Dawson's statement that the source of the Lewes is more distant from the

sea than the source of the "Tes-lin-too" seems premature, as neither of these streams has been fully explored, and their sources are unknown.

In view of the facts just stated, it seems to me advisable to apply the name Yukon to the main trunk of the drainage system, commonly known by that name in the lower part of its course—that is, that the Yukon, the Pelly, the Lewes below the mouth of the Tes-lin-too, and the Tes-lin-too to its source, as designated by Dawson, be named the Yukon.

Geological Structure of the Yukon Region.

Monoclinals.—The prevailing trend of the mountains and the strike of the rocks throughout the Yukon region below the mouth of the Porcupine is, in general, northeast and southwest. Along the Yukon, near the 141st meridian and in the neighboring part of the North West Territory, the trend of the main ranges is nearly east and west. Throughout the Yukon region in Alaska the geological structure approaches that of the Great Basin of the western United States. Nothing similar to the folds of the Appalachians or the Alps has been observed in that region. The mountains are, in large part, monoclinal ridges, but do not reveal their structure as definitely as do the ranges of Nevada and Utah. The presence of faults along the borders of the upheaved orographic block can be readily determined, however, in many instances.

Faults.—The finest example of monoclinal structure seen in ascending the Yukon, though on a comparatively small scale, was in cliffs of sandstone and slate bordering the right bank of the river for several miles, at a locality some fifteen or twenty miles below the mouth of the Meloikakat, or midway between Nulato and Nowikakat. These sandstones contain the leaves of deciduous trees and belong to the same system as the rocks at Nulato, which have been described by Dall.*

The river bank at the locality referred to is extremely precipitous, and exposes a fine section of the rocks, which dip, in general, northwest 25° to 30°, except where disturbed by faults. The displacements trend nearly north and south and appear in the cliffs as in a diagram. In the best exposed portion of the section there are six or eight important faults within a space of about two miles. These are parallel and head to the east at angles ranging from 25° to 40°. In each instance the strata are disturbed on approaching the breaks, but soon return to their normal dip. At each fault a lateral valley has been excavated, the west side of which is a smooth, even, rock slope, frequently slickensided, and is in reality the heaved side of the fault. The east wall of each of the valleys is rugged and broken, and the strata in the projecting ledges usually show a high dip towards the east. In other

*Am. Jour. Sci., 2d Ser., Vol. 45, 1868, pp. 97–98.

ravines, where the structure was not clearly visible, the peculiar topographic conditions indicated a similar origin. These faults are instructive for the reason that they illustrate the manner in which a series of displaced blocks sometimes present a nearly uniform dip, so as to appear as a single monoclinal when the exposures are not sufficient to show the true structure.

Joint-valleys.—The rocks in the precipitous bluffs of the Yukon exhibit a pronounced jointed structure in many localities. As in other regions, the joints occur in systems which cross each other at various angles. Their influence on topography is sometimes plainly traceable not only in the pyramidal form of rocky pinnacles, but in the contour of the valleys which separate them. In a number of instances two main systems of joints exist which at their intersection with a horizontal plane form parallel lines, but are so inclined as to meet below the surface at an angle of twenty or thirty degrees. When this occurs the prism of rock bounded by the joint planes and the surface of the land has sometimes been eroded out, leaving a sharply defined V-shaped valley of low grade. When so situated as to open in the tops of high bluffs along the Yukon, these valleys discharge their water in cascades into the river below.

The origin of certain low-grade lateral valleys in the glaciated portion of the High Sierra of California, which open high up in the bluffs bordering larger valleys and discharge their waters in cascades, has never been satisfactorily explained. The fact that similar valleys in a non-glaciated region have resulted from the weathering of jointed rocks may help to account for these peculiar topographic forms. Should the joint-valleys along the Yukon be occupied by local glaciers their forms would be modified principally by a broadening of their bottoms, and they would resemble still more closely the smaller of the high lateral valleys of glaciated mountains.

Bluffs on the Upper Yukon.—The most remarkable bluff on the Yukon is about twenty-five to thirty miles west of the international boundary, on the left bank of the stream. This is a sheer precipice of contorted slate, about 600 feet high and more than a mile in length. The beds are seldom more than a few inches thick, and composed of black, somewhat metamorphosed slates, separated by yellowish-white layers. The strata are much contorted and broken by small faults, along which a peculiar crumpling of the slate has occurred. The general dip is toward the west. The cliffs terminate abruptly at the east end, where they are cut off by a bold scarp trending at right angles to the river. This scarp is mostly bare of vegetation, trends N. 60° E., and slopes east at an angle of about 60°. It is really a fault-face of so recent origin that it is not yet covered with vegetation. The steep slope of the fault scarp has a pinkish color, seemingly due to débris of certain red rocks which, when undisturbed, occur above the contorted strata.

The series of contorted slates forming the great bluff mentioned may be

seen for several miles along the river, both above and below it. They were observed also on the Porcupine river, nearly due north of the locality here mentioned.

Immediately at the international boundary there are bold bluffs on each side of the river, with mountains about 3,000 feet high rising back of them. The ranges are serrate, trend nearly east and west, and are composed of limestone in nearly vertical strata. The river follows the south base of one of these limestone mountains for fully fifty miles east of the boundary. As seen from the river, this range seemed to be monoclinal in structure.

Near Forty-mile creek, and from there a long way up-stream, the banks are in general of metamorphic schist with quartz veins. The rocks form bold pinnacles and headlands along the river, leaving no room for a flood-plain at their bases.

My notes on the rocks of this region are meagre, owing to the lack of opportunities for personal examination on shore, and I have withheld much that I noted concerning the "hard geology," fearing that my hasty observations might be too much in error to be of value.

Geology of the Yukon River.

THE DELTA OF THE YUKON.

General Character.—The delta of the Yukon, as shown by such examinations as have been made, is about 125 miles in length, the apex being where the river first divides on approaching its mouth. The periphery of the delta, not including minor sinuosities of the shore-line, is approximately 150 miles. This embraces, however, some highlands, which rise like islands in the broad, nearly level expanse of sediment that has been spread out by the river.

I first saw the delta near the entrance to the Aphoon branch. This is the most northerly channel by which the Yukon discharges into the sea. The land is there low and swampy, and intersected by muddy sloughs and tide-ways. It is bare of trees, but covered by a most luxuriant growth of mosses and lichens. The meadow-like expanse is dotted everywhere with ponds and lakelets. This is a part of the great tundra belt that skirts the entire northern and western shores of Alaska, the characteristic features of which are described elsewhere in this paper.

Drift Timber.—The border of the delta and the banks of the numerous water channels that intersect it are fringed with drift-wood. Débris of similar character is exposed in such abundance in freshly formed river escarpments as to render it evident that the entire delta contains a more or less continuous substratum of trunks, branches and roots of trees, embedded in river silt.

Above the timber layer there is a deposit of silt or clay, and covering this is the peaty layer of the tundra.

While ascending the Yukon many trees and portions of trees were seen drifting with the current, or stranded on the banks of the river, especially on the upper ends of low islands, and where sloughs leave the main river. At such localities there is not infrequently an acre or two of weather-beaten drift-logs, piled together in a most confused manner and having a depth, by estimate, of fully twenty feet in some instances. The banks of the Yukon and of its tributaries are densely forested, and as they are cut away by the swift currents, furnish an unlimited supply of timber for the river to transport.

The abundance of drift-wood along the banks of the Yukon or traveling with its current explains the source of the many derelicts of the land observed during the voyage from Unalaska to St. Michaels. The most of the abundant drift-wood of Behring sea is undoubtedly derived from the Yukon and Kuskokwim rivers. The shores of Behring sea are treeless throughout, but are almost everywhere fringed with drift-wood. The wood thrown ashore by the waves furnishes the only supply of fuel and building material for the natives at widely separated localities, both on the mainland and on numerous islands. At St. Michaels the supply of wood for fuel, both for the residents and for the small steamboats, is gathered from the beach. A large part of the fire-wood used on the steamboats which navigate the Yukon is cut from drift timber. In the sediments now being spread over the bottom of Behring sea, water-logged drift-wood, principally spruce, must be of frequent occurrence.

Surface of the Delta.—About forty miles up the river I made a short excursion inland and had an instructive view of a typical portion of the delta. The immediate bank of the river at this point was low and swampy and clothed with a dense growth of alders. The fringe of brush was half a mile broad and terminated landward against a bluff about thirty feet high. Ascending the bluff, I had before me a seemingly boundless expanse of moss-covered land, without a tree or conspicuous shrub to relieve its monotony. Here and there on the dreary moorland were lakelets, frequently circular in outline and surrounded by flowery banks of moss. The soil beneath the thick brown-green carpet was a dark humus, formed entirely from the decay of the tundra plants. The thickness of the humus layer was not determined; below the depth of about a foot it was solidly frozen.

The conditions here briefly described continue to characterize the land bordering the Yukon on either hand for a distance of sixty or seventy miles from its mouth. On the right bank the inland border of the tundra is reached a few miles below the village of Andreieffski. The land there rises into hills and the spruce forest begins. The soil is a stiff clay, probably a continuation of the substratum of the tundra.

At Andreieffski the river, or rather the Aphoon branch of it, is nearly two miles broad, and, as is usual throughout the lower Yukon, is cutting its right bank. The difference between high and low water is about five feet.

Throughout the portion of the Yukon delta that I saw, but which must be characteristic of its entire extent, there are many abandoned channels and old water-ways, some of which contain lakelets. The greater part of the lakelets on the tundra, however, originated in other ways. See page —. The abandoned channels show that the stream is unstable and subject to many changes. This is also known from the experience of the steamboat captains, who have been familiar with the region for many years.

THE BANKS OF THE YUKON.

Erosion of the Right Bank.—After entering the Yukon river proper—that is, after passing the head of the first or highest branch which meanders through the delta—the right bank is usually high and bold, while the left bank is commonly bordered by lowlands. The fact that the Yukon throughout the lower portion of its course is cutting its right bank has been mentioned by Dall and others and need not be discussed farther at this time.

The right bank is frequently bold and rocky, and at times forms palisades, all the way from the head of the delta to the Koyukuk, about twenty miles above Nulato. Above that point the river flows through broad, swampy lowlands for seventy or eighty miles, and then the Lower Ramparts begin; both banks become higher and frequently form bluffs and headlands of great beauty.

Lower Ramparts.—In the Lower Ramparts there are high lands on each side of the river. The stream is greatly reduced in width, is without islands, and flows swiftly. The scenery is wild and picturesque, but scarcely more impressive than the Highlands of the Hudson.

Lowlands.—Above the Lower Ramparts for a distance of about 250 miles the Yukon flows through a low, densely wooded region, which is frequently swampy and widely overflowed during spring freshets. The river spreads out into many branches, which unite and divide so as to enclose thousands of islands.

The breadth of the lowlands on each side of the stream is unknown, but in ascending the river the bordering highlands were frequently so distant that they could not be seen from the steamboat's deck. The conditions just described extend for fully one hundred miles up the Porcupine river. This river, however, does not divide so as to enclose islands, but forms a single very tortuous channel where it cuts its way through the lowlands.

The great flatlands just described are of interest, as they indicate recent changes in the geography of the region. Everywhere through them there are abandoned stream channels, showing that probably the entire region

including the numerous islands as well as the bordering country for many miles, has been traversed by the river and is, in fact, a vast flood-plain deposit.

The sections referred to in the newly eroded banks show current-bedded gravels and sands, with occasional interstratified layers of peat similar to that now forming the surface layer beneath the forest.

On looking down on the lowlands from hills near their border—the best view that I obtained was from the summit of a hill about one hundred miles up the Porcupine—one sees winding lanes opening out through the forest, carpeted with bright green Equisetums, and overshadowed by tall spruce trees or slim, gracefully bending willows. These picturesque lanes mark the positions of recently abandoned water-courses. The most recent of these old channels still hold ponds and sloughs, about which the moss grows with great luxuriance. Those of older date are indicated by a change of tint or a variation in the luxuriance of the forest trees, and may be easily recognized in a wide-reaching view.

The vegetation on the lowlands is composed mainly of spruce trees, growing close together and attaining a height of sixty or seventy feet or more. Along the stream willows and alders are common, and wild roses bloom in luxuriance in all of the more open spaces. Beneath the trees and dense undergrowth there is a thick, soft carpet of lichens and mosses, in which thousands of lovely flowering plants unfold their blossoms and ripen their brilliant fruits. Beneath the moss there is usually a layer of vegetable mould or peat, ranging from a foot or two to many feet in thickness. Its maximum depth is unknown. Beneath the immediate surface the peaty layer is frozen throughout the year. It rests either on strata of loose material, as sand or clay, or immediately on the subjacent solid rock. The dense forest of spruce rising above the moss is about all that distinguishes the low swamp lands along the Yukon from the tundra of the coast. There are differences, however, in the luxuriant, cryptogamic floras of the two regions, which are sufficiently obvious on close examination.

The undermined and crumbling banks of the Yukon and tributary streams, where they flow through the swampy lowlands, frequently exhibit sections of ancient peaty layers, which are solidly frozen, and also the edges of strata of clear ice. The trees growing on the undermined banks frequently lean far over and dip their tops in the current before being finally carried away. At times large blocks of the bank cave off and carry a number of trees bodily into the river, where they sometimes remain standing half submerged for a whole season. These slides are usually preceded by a crevassing of the bank in lines parallel with its edge and distant some twenty or thirty feet from it. The carpet of moss and rootlets that occurs throughout the lowlands, and, we might say without exaggeration, throughout Alaska, is so tenaceous and

so closely woven that when the river borders are washed away it hangs from the top of the bank like a curtain, as if intended to hide the ruin the waters had made.

The greatest expanse of the Yukon lowlands, as already mentioned, occurs just above the Lower Ramparts, and extends some 250 miles to the eastward; its breadth may be roughly estimated at from 75 to 100 miles. At the Lower Ramparts the river is greatly contracted, and is now deepening its channel. The explanation of the presence of the lowlands above the Lower Ramparts seems to be that orographic movement is taking place, and a mountain range is being raised athwart the river. Above the obstruction the river has spread out a broad flood-plain, through which it meanders. This is only a suggested explanation of the origin of the lowlands. No opportunity was afforded for studying the matter in detail. It is possible that a broad lake has existed above the Lower Ramparts, but no beach lines were observed on the hills which would have formed the border of such a lake, and besides, the material exposed in the river banks does not suggest the presence of lacustral conditions during its deposition. The lack of evidence of the former presence of a lake, as well as the positive evidence of flood-plain conditions, leads me to suppose that obstruction of the drainage by orographic movement would account for all the conditions noted.

Whether a similar relation of lowlands to river narrows occurs in the case of the swampy areas below the Lower Ramparts or not is uncertain. The broad, moss-covered region of the delta belongs to another category and need not be considered in this connection.

Highlands of the Upper Yukon.—Above the lowlands through which the Yukon and Porcupine rivers flow near their junction, the banks of the Yukon are bold, and usually rise abruptly from the river. Many of them rise like sea-cliffs directly from the water's edge to a height of four or five hundred feet, and can not be passed even by a person on foot. About their bases the river sweeps with such force that the ascent of the stream in a small boat is exceedingly difficult.

As one continues to ascend, the terraces on the borders of the stream become more and more prominent, until near the mouth of the Pelly river, and thence to the lakes on the Lewes they form an important element in the landscape.

At the mouth of the Pelly, and for several miles below, there is a bold palisade on the right bank, formed by a basaltic escarpment some three or four hundred feet high. This is the edge of a table-land, formed by a lava flow which filled the valley and extended several miles up the Pelly. The Yukon in excavating its channel occupied the line of junction between the lava coulée and the bold left bank of its former valley. The Pelly also followed the border of the coulée along its eastern edge.

At the international boundary the Yukon flows through an exceedingly

rugged country, in which the mountains, composed largely of limestone, trend nearly east and west, and are exceedingly sharp and rugged. The river here flows with the strike of the rocks, but yet has only a very limited amount of low land along its border. Near the mouth of Forty-mile creek and for a long distance above, the rocks are a metamorphic schist, which form bold rugged cliffs along the river, and afford some of the finest scenery on the Yukon.

At the mouth of the Lewes the country is more open; the hills are bold, with rounded summits, and the characteristics of a glaciated region replace the angular mountain forms so typical of the Lower Yukon country. About Lake Lebarge, especially, the rounded, flowing outlines of the hills bear unmistakable evidence of intense glaciation. In ascending the Lewes the scenery increases in grandeur until the snow-covered summits of mountains along the southern coast of Alaska come in view. The many lakes of this region add an attractive feature to the scene and enhance the magnificence of the mountains surrounding them.

THE WATER OF THE YUKON.

Muddy and Clear Tributaries.—The larger streams tributary to the Yukon and to the Lewes from the south—viz., the Tananah, White, and Tahk-heena rivers—are heavily loaded with silt and have all of the characteristics of glacial streams. All of the tributaries of the Yukon from the north, and also the smaller streams from the south, are clear; but some of them are dark with organic matter derived from the swamps and moss-covered areas through which they flow. These characteristics of its tributaries indicate at once, and the conclusion is sustained by other evidence, that all of the glaciers within the Yukon drainage system are located along its southern border.

The Yukon below the mouth of the Tananah is intensely muddy, and derives a very large part of its sediment from that river. Above the mouth of the Tananah it is still very turbid, and holds this character to where White river empties in its heavily loaded flood. Above that point it is practically a clear stream, but still has a slight milky turbidity, which gives its water a milky or opalescent tint. This slight discoloration is due to sediment contributed by the Lewes. At the junction of the Yukon and the Lewes a marked contrast in the color of the two streams is especially noticeable. The Yukon above the junction is clear and dark, while the Lewes is decidedly milky in appearance. This contrast has been noted by Dawson,* who observes: "The water of the Lewes has a blue, slightly opalescent color, much resembling that of the Rhone where it issues from the lake of Geneva, while that of the Tes-lin-too [Yukon] is brownish and somewhat turbid."

* Rep. Yukon District, loc. cit., p. 153B.

The principal source of the fine sediment that discolors the Lewes below Lake Lebarge is derived from the Tahk-heena river, which has its source among the glaciers near the Chilkat pass and joins the Lewes just above Lake Lebarge. The extreme fineness of the sediment which discolors the waters of Lake Lebarge and of the streams flowing from it will be appreciated when it is remembered that although the lake is nearly thirty miles long the waters passing through it are not completely cleared by sedimentation.

The waters of the numerous lakes along the course of the Lewes above Lake Lebarge are also more or less turbid with silt. Their turbidity increases as one approaches the Coast Range, on which are many glaciers, and it is evident that the sediment in the lakes and streams is due directly to the abrasion of the rocks by glacial ice. The waters of Lake Lindeman, especially, are densely turbid and have a greenish-white color. The upper portion of Lake Bennett is similarly discolored. As these waters pass down through lakes Tagish and Marsh they become greatly clarified, but still retain sufficient fine silt to reveal their glacial origin.

Sediment in Suspension.—While ascending the lower Yukon five samples of the water of the river, of a liter each, were collected at the localities given below, and the weight of sediment they contained determined. The results of this investigation are as follows:

Sediment in the Water of the Yukon.

	Locality.	*Date.*	*Grams in a liter.*
Below mouth of the Tananah.	Lofka	July 22, 1889	0.9817
	Nulato	" 24, "	1 1147
	Nowikakat	" 25, "	0.7783
Above mouth of the Tananah.	Entrance of Lower Ramparts	" 27, "	0.2754
	Five miles above Lower Ramparts	" 28, "	0.2078

No determination of the volume of the Yukon was practicable during my journey, but it is expected that Messrs. McGrath and Turner will make such measurements during their descent of the river in 1890. When the results of their observations are known, the data given above will enable one to form a rough estimate of the amount of material that is being carried in suspension from the land to the sea by Alaska's great river.

GEOLOGICAL RECORDS NOW BEING MADE BY THE YUKON.

The River in Winter.—My experience on the Yukon is limited to a brief summer trip. For information concerning its behavior in winter I am indebted to many miners and traders, and especially to Arthur Harper, who has passed many winters in central Alaska and the adjacent portion of the North West Territory.

Like many northward-flowing rivers, the Yukon is closed by ice first at

its mouth, and in the spring opens first at its head. Near its mouth it is closed each year about the middle of October, but has been known to remain open as late as the first of December. As winter approaches, ice forms along its sides, leaving open water in mid-channel or where the current is swiftest. The fringe of ice first formed is smooth, and can be easily traversed. As the river falls, however, during the winter, it becomes much broken, and in many instances quite impassable. When the cold is sufficiently intense to completely close the river mouth, the swift current packs the new slush-ice, and cakes broken from the sides, against this ice bridge. This process continues progressively up-stream till the river is completely ice-covered from mouth to source. The freezing of the lakes on the upper waters of the Yukon, I have been informed, is frequently delayed until December.

From the manner in which the swifter portions of the river become ice-covered, as well as from the breaking and subsidence of the ice due to the shrinking of the river in very cold weather, the frozen river is almost always rough and difficult to travel over.*

The thickness of the ice on the lower river is stated by several residents to be generally from ten to fifteen feet. Some of the tributaries of the Yukon, which are veritable rivers in summer, are frozen solid to the bottom during winter. In Forty-mile creek placer mining is carried on in winter by cutting away the ice and thawing out the frozen gravel beneath by means of large fires. The auriferous gravel is removed to the bank of the stream and washed when warm weather returns.

Spring Freshets.—In spring the river thawing first at its head frequently initiates floods and ice gorges of great magnitude. At times the water behind an ice dam rises thirty or forty feet, and if the bank of the river chances to be low, inundates large areas. During these freshets immense quantities of ice are borne along by the swift current and lodged in heaps on the river banks. The annual movement of such large quantities of ice is accompanied by results of geological interest.

Rock Surfaces polished and scratched by River Ice.—The banks of the Yukon where they are precipitous are frequently smoothed and polished in the space between high and low water. The surfaces best showing these characteristics are on the up-stream side of bold promontories. In such localities the smooth surfaces are not infrequently scratched in an irregular manner. The scratches are rudely parallel to the direction of the river current, but are not deeply engraved. On the down-stream side of projecting rocks and cliffs the surfaces are rough and without striations. These records are clearly due in large part to the friction of ice descending the river. The scratches are made by sand and pebbles frozen in the ice.

* The behavior of northern rivers in winter has been described by A. C. Anderson, in Jour. Roy. Geograph. Soc. London, Vol. 15, 1845, pp. 367-371.

Bowlders Transported by River Ice.—The first large bowlder that I saw in ascending the Yukon, the travels of which could be approximately measured, was on the left bank of the river, about fifteen miles above Nowikakat. This is a granite bowlder, measuring 4 by 3 by 3½ feet. The ledge from which it must have been derived is in the Lower Ramparts, about one hundred miles above its present position. Other bowlders, many of them larger than this, were seen at many localities, but the distances they had traveled were not ascertained. The largest one measured was near McGrath's Station. It is composed of dark, volcanic rock, is rudely spherical, and measures a little over six feet in diameter.

Bowlders were frequently observed just above high-water mark, where the river banks are low and composed of sand and gravel. These had evidently been forced landward by ice pressure during the breaking up of the river in spring. The furrows plowed during their advance, as well as the bank of sand and gravel accumulated in front, could still be distinguished. The force which moved these bowlders was plainly the river ice. When the direction of movement could be determined, it was always found to have been down stream, but at the same time trending away from the river at an angle of from 30° to perhaps 50°. The direction of movement, as well as the fact that the bowlders occur at high-water mark, and often a little above that horizon, shows that they must have been disturbed at the time when the river was at its flood stage, and expanding so as to force ice over its banks.

It is well known that when a river is rising the drift-wood it carries tends to travel towards the shores, and frequently becomes entangled in the vegetation on the banks. When falling, the drift-wood tends towards the line of swiftest current. A similar rule controls the direction taken by the floating ice during spring freshets. I have been informed by persons who have witnessed the breaking up of the Yukon in spring, that ice in immense cakes is frequently forced up on the shore to a height of ten or fifteen feet, and remains long after the river has fallen and is clear of ice. It is during the accumulation of such ice heaps that bowlders are moved in the manner described above. Scars and marks of abrasion, due to ice, are frequently seen on tree trunks at a height of ten feet or more above the high-water line of the river.

Furrows in the sands of the river banks which had been formed by blocks of ice forced shoreward in the same manner as the bowlders just described were observed at many localities. In these instances the shapes of the ice cakes could be clearly distinguished in the banks of sand, frequently three feet or more in height, that had been forced up in front of them. From the manner of formation it is obvious that the furrows made by bowlders and ice as just described are transient features, obliterated and renewed at each breaking up of the river.

Gravel Heaps deposited by River Ice.—On the low, sandy shores of the Yukon, especially on the up-stream ends of low islands, there are frequently heaps and ridges of gravel accumulated by the ice. The simplest of these deposits are heaps of rounded, water-worn stones and bowlders, resting on a sand flat. They are of all sizes up to those containing two cart-loads or more of material. Down-stream from those heaps which occur below high-water mark, there is frequently a trail of fine sand, tapering to a point some fifteen or twenty feet distant, showing that water has flowed over them and deposited sand in the eddy below.

In other instances, also quite common on low, sandy shores, the gravel was arranged in ridges a few inches high, which intersected and crossed one another so as to enclose bare, slightly basin-shaped spaces, from a few inches to several feet in diameter. Sometimes these ridges of gravel bore a fanciful resemblance to letters, as if some one had tried to write an inscription on the sand by piling up lines of gravel. Again they were more regular, and enclosed depressed areas that looked not unlike gigantic tadpole nests. These resemblances, however, are mere fancies.

The explanation of the presence of the ridges and of the gravel heaps is to be found in the action of ice on the river banks during high water: The ice adheres to the bottom of the river in many places during the winter and is floated away in large cakes when the spring freshets come. The bottoms of the cakes are charged with gravel, and when they run aground on low shores, as often happens, and are melted, their load of stones is left behind. In the heaps of ice formed on the shore the blocks are frequently turned on edge, and on melting in that position leave the low ridges of gravel described above.

When low, sandy shores are covered with cakes of ice, leaving cracks between, the gravel transported in the manner described finds lodgment in the cracks, and when the ice melts forms ridges, some of which intersect and enclose bare, sandy spaces.

Pebbles Faceted, Polished, and Scratched by River Ice.—The most interesting records made by river ice in Alaska occur on pebbles that are set in a matrix of tenacious clay, and form a pavement along the river banks. A typical instance of this nature was observed on Porcupine river about one hundred miles above its mouth. At this locality the steep bluff overlooking the river is formed of tenacious blue clay and capped by a layer of water-worn pebbles of various kinds and sizes. The pebbles on falling to the river beach become imbedded in clay so as to form a veritable pavement along the river over a space about one hundred feet broad during low water and more than a mile in length. The upper surfaces of the pebbles set in the clay have been ground down or faceted. The surfaces of the facets are smooth and crossed by striations which are in general parallel with the

course of the river. The pebbles thus marked resemble glaciated pebbles so closely that I took special pains to determine the origin of their peculiar markings. Only the upper surfaces of the pebbles taken from the pavement were abraded. Moreover, no pebbles showing the markings referred to were found above high-water mark. That the pebbles were ground down, polished and striated by the river ice passing over them during its descent of the river is plainly apparent.

Some of the stones in this pavement are angular masses of basalt, nearly two feet in diameter. These, like the associated pebbles, are deeply abraded and scratched in rudely parallel lines. On some of the rounded pebbles the amount worn off on the abraded side was estimated to have been about half an inch.

Many of the stones in this locality are so similar to glaciated pebbles that if removed from their normal position to a glaciated region, even the most acute observer would attribute their markings to glacial action. When, however, one knows the origin of the markings upon them it becomes evident that the scratches on the smooth faces are less regular and less firmly drawn than the grooves and striations on typical glaciated pebbles.

"Bowlder Clay" deposited by Rivers.—The Yukon, as already stated, freezes deeply during the winter, and the ice near its borders, especially where it is broad and shallow, rests on the bottom, and has large quantities of stone and bowlders attached to it. All except the largest of the tributary streams freeze to the bottom, and also furnish vast quantities of pebbles for ice transportation. When the rivers break up in the spring, the ice with its loads of stone is floated down-stream, and, melting as it goes, distributes pebbles and bowlders over the bottom of the river, and in places where at other times fine sediment is deposited. In this manner it is conceivable that a clay filled with bowlders might be formed which would similate true bowlder clay in many ways. Certain bowlder clays along the Yukon and the Lewes are described elsewhere in this paper, which, as there stated, may have been formed in the manner here suggested.

Old Deposits of ice-borne River Gravel.—The past action of the river ice in transporting stones is recorded by deposits of bowlders in lenticular masses in the fine sediment exposed in the river banks. Isolated bunches of gravel wholly enclosed by fine sediment, and ten to fifteen feet below the surface, are not unusual in the caving river banks. In some places large bowlders were seen in like situations. These occurrences are satisfactorily accounted for on the hypothesis that the gravel and bowlders in question were transported and deposited by river ice.

Flood-Plain Deposits.—The manner in which rivers build up, destroy, and rebuild their flood-plains can be studied to advantage at many places on the Yukon and Porcupine. The lower hundred miles of the latter offers an

especially interesting region for such study. This portion of the Porcupine flows through a low, densely forested region, which is an extension of the lowlands of the Yukon already described. Its course is extremely tortuous, and in fact forms a continuous series of gracefully sweeping curves. In its meanderings it cuts away the banks on its concave side, and deposits the material removed lower down on its convex side. In this way a marked contrast in the character of its banks has been produced. On the outer curves the banks are precipitous, owing to the undercutting of the river. They are uniformly about twenty feet high, and densely covered with fully grown spruce trees. The river has cut a swath through the forest and left the trees standing on its border as the grain stands beside the path of the reaper.

On the inner curves the banks are low and gently sloping, and near the water are bare of vegetation. Proceeding up the shelving shore, one comes first to coarse grasses and yellowish-green Equisetums. Beyond this belt is a growth of young willows, which increase in height away from the river, and soon form a dense growth thirty or forty feet high. Mingled with the willows and replacing them on the landward side are clumps of alders and groves of poplars. Beyond this belt lies the unexplored spruce forest, which stretches away for miles and densely covers the land to and beyond the distant hills.

The immediate border of the river on the convex curves is formed of current-bedded gravels. Going up the beach one comes to sand banks, which in their turn pass beneath deposits of fine silt. These are the flood-plain deposits of the river, and are arranged in a definite sequence resulting from their mode of deposition. The gravels are deposited by the swift waters along the border of the main channel, while the finer superimposed strata are spread out by the slack water on the margin of the stream during its flood stages.

Fresh-water shells were frequently observed in the finer deposits. Cross-bedding, common in all the strata, is best defined in the coarse deposits. At times the sand and silt layers are finely laminated, and may closely resemble lacustral deposits. In one instance a layer of coarse sand more than twelve feet thick was observed. Though deposited by the river it was homogeneous throughout, and did not exhibit a single line of stratification or cross-bedding.

As the river slowly changes its course by taking from one bank and depositing on the other, the sheets of débris it spreads out are increased by additions to their margins, preserving at the same time their order of superposition.

Within the forest there is a dense growth of mosses and lichens, decaying beneath while growing above. This process superimposes a layer of peat on the deposits spread out by the river. The soil is everywhere frozen at a depth of about a foot below the surface.

A section of the flood-plain deposits of the Porcupine where no complications occur presents the following divisions in their natural order and approximate thicknesses:

Peaty layer	2– 3 feet.
Fine silt	3– 5 "
Sand	3– 6 "
Coarse current-bedded gravels and sand	15–30 "

The continuity of the strata just described is broken when the river cuts across a bend, as frequently happens, and a new series of deposits is begun.

A decrease in the grade of the stream from any cause, as orographic movement for example, would admit of the superposition of one flood-plain series upon another. An occurrence of this nature seems to have taken place in the lowlands of the Yukon above the Lower Ramparts, where a layer of peat is interstratified with current-bedded sands and gravel. An increase in the grade of the stream would enable it to deepen its channel and leave portions of its flood-plain as a terrace along its borders. A similar record would be made by a stream descending a stable declivity, by the erosion and deepening of its channel, thus leaving portions of its flood-plain to record horizons at which it remained for a considerable time.

Terraces along the Upper Yukon record the fact that the stream at one time flowed several hundred feet higher than at present, and in deepening its channel, probably on account of orographic movement, left portions of its flood-plain on the sides of its valley.

Mammoth Remains in the Banks of the Yukon.—Teeth and tusks of the mammoth, associated with large bones, are reported to occur in abundance at two principal localities along the Lower Yukon. I was not fortunate enough to find any of these fossils myself, but saw several that had been found by others. One of these localities is near the head of the delta, but I was not able to learn its exact position. The other is on the left bank of the river between Nowikakat and Nuklukahyet, about forty miles below the mouth of the Tananah. Its position is indicated by the word "Palisades" on the U. S. Goast and Geodetic Survey map of "Alaska and Adjoining Territory," and on the small map (pl. 2) accompanying this paper.

The bluffs at the Palisades are approximately three hundred feet high, level topped, and composed of fine, light-colored, evenly stratified sediments. Back from the bluffs is a level, densely wooded table-land, with swamps and ponds, bordered on all sides, except that adjacent to the river, by bold hills. The Palisades proper are washed by the river, and form precipitous bluffs entirely bare of vegetation. The same escarpment extends some ten miles up the river, clothed with vegetation, and with a densely wooded flood-plain along its base. The portion of the escarpment now washed by the river,

according to Captain Charles Peterson, of the steamboat "Yukon", is composed of frozen "sand." The fact that the strata are frozen accounts for the steepness of the escarpment. As the river washes away its banks, large numbers of bones, teeth, and tusks are exposed. I was informed also by Peterson that the deposit near the delta is of the same general character as the one here described.

The position of the strata forming the bluff at the Palisades, as well as their regularity of stratification and fineness of material, indicates a lacustral origin. What is known of their fossils suggests Pleistocene or Tertiary age.

The banks of the Yukon in the lowlands above the Lower Ramparts, and at many localities lower down stream, are formed of flood-plain deposits and are much more recent than the high bluffs at the Palisades. From this, together with what I learned concerning the occurrence of detached bones, teeth, etc., at many places along the Lower Yukon, it seems very probable that they were not in the original place of interment, but had been washed out of the bluffs at the Palisades, or other similar deposits, and transported down stream. Similar bones have been found above the Palisades, however, and I suspect that other "bone beds" exist higher up the river.

It is necessary to note that the statements just made do not seem to harmonize with the observations of Dall and others, who found mammoth remains in the earthy layer on top of the ice cliffs near Kotzebue sound. The vertebrate fossils in the stratified beds at the Palisades certainly seem to be older than the similar remains occurring on the surface of the tundra.

Extinction of the Mammoth.—It is an interesting fact that all the bones of the mammoth and of other large animals that have been found in Alaska occur, so far as I am aware, in regions not glaciated during the Pleistocene period.* The relation of mammoth remains to the distribution of glaciers in Alaska acquires additional importance in view of the fact that no evidence of glaciation has been reported in northern Siberia, where similar mammalian remains are also abundant.

The study of glacial records by various observers has shown that the great Pleistocene glaciers of this continent extended outwards in all directions from two main centers of accumulation, one in Labrador and the other in the northern part of the Rocky Mountain region. During their greatest extention these two great glacier systems seem to have been confluent, so that a vast ice field stretched across the continent from ocean to ocean. The northward movement of the ancient ice sheet was not sufficient in all places to reach the Arctic ocean. In view of this fact, it may be suggested that the abundance of mammalian bones in the nonglaciated regions in the far North is due to the crowding northward and final extinction of land

* The absence of glaciers in central and northern Alaska is discussed elsewhere in this paper.

animals of the Pleistocene period by the advance of continental glaciers from the south.

I venture to suggest that a similar sequence of events will appear in the later geological history of Asia when the surface geology of that continent is more fully investigated.

Preservation of Fish Remains.—The annual migrations of the salmon in the rivers of northwestern North America are of interest to the geologist, since they die in vast numbers and are buried and preserved in the sediments now forming.

I saw large numbers of dead salmon in the upper Yukon and in the Lewes. The largest number seen was, however, in the Taiya river, near its mouth. At this place the "dog salmon" were crowding up the stream in thousands, and thousands that had previously made the ascent were already dead. The Taiya river has several mouths, and the water in many of these was so shallow at the time of my visit that the backs of the salmon were exposed as they persistently worked their way up stream. The waters were falling, so that many pools and sloughs had ceased to be connected with the main stream. In these somewhat stagnant waters the fish were concentrated so as to completely conceal the bottom. The water from the river that reached these pools, already partially filled with mud, was charged with glacial silt, and a deposit of fine sediment was being formed about the dead fish, which might, under favorable conditions, completely bury them. Large numbers of dead fish also floated down stream, and must finally have sunk to the bottom in salt water. As the delta of the Taiya is growing rapidly, the conditions for preserving large numbers of fish, belonging to a few species, are exceedingly favorable.

The occurrence described is in no way exceptional or novel, but takes place every year in many places. It serves, I believe, to explain the presence of large numbers of fossil fishes in certain rocks, as, for example, in the Newark system, near Boonton, New Jersey, where fishes of a class that now inhabit rivers and lakes occur packed together by hundreds, if not by thousands, in a fine shale associated with coarse conglomerates.

NAVIGATION OF THE YUKON AND ITS TRIBUTARIES.

Captain Peterson ascended the Yukon last summer with the steamboat "Yukon" as far as the mouth of Pelly river, which is about one hundred miles farther than any steamboat has hitherto gone. The trip up the Porcupine was the first venture of a steamboat on that river.

In ascending the Porcupine we left Fort Yukon in the forenoon of August 3, and reached the limit of navigation, about forty miles below the Rampart House, at noon on August 6. Had the ascent been made a few days earlier, a greater distance could have been navigated, because the water had recently

been much higher. At the time of our visit it was rapidly falling. The return trip to Fort Yukon was made in about eighteen hours.

The "Yukon" did not pass the mouth of Pelly river, as that was her destination. She might easily have done so, however, had it been desirable. She could have ascended the Yukon to and beyond the mouth of the Lewes, and could also have ascended the Lewes as far as White Horse rapids, just below Miles cañon. The only place below White Horse rapids which seems to offer special difficulty is at Rink rapids (Five Fingers), where the river is obstructed by islands and the current is very swift.

Above Miles cañon the river is navigable for small steamboats all the way to lakes Tagish and Bennett. The grand scenery of the numerous lakes drained by the Lewes would attract many tourists should steamboats be placed on them.

THE TUNDRA.

GEOLOGY OF THE TREELESS, MOSS-COVERED SHORES OF ALASKA.

Definition.—The name "Tundra" is used in Siberia to designate the vast, treeless, moss-covered plains bordering the Arctic ocean and has been adopted for the similar regions fringing the northern shores of North America.

A general knowledge of Alaska derived from many sources* renders it evident that the tundra occurs all along the borders of Behring sea and the Arctic ocean. My observations concerning it were limited to the region about St. Michaels, to the delta of the Yukon, and to the less typical shores of Unalaska.

General Characters.—The tundra in typical localities is a swampy, moderately level country, covered with mosses, lichens, and a great number of small but exceedingly beautiful flowering plants, together with a few ferns. The soil beneath the luxuriant carpet of dense vegetation is a dark humus, and at a depth exceeding about a foot is always frozen. On its surface there are many lakelets and ponds surrounded by banks of moss even more luxuriant than on the general surface. It is not always a level plain, however, but is frequently undulating and may surround and completely cover hills of considerable elevation. The dense tundra vegetation also extends up the mountain side and occupies the entire region where the conditions are favorable for its formation. At the localities where I examined it the whole surface, excepting the faces of steep cliffs and the summits of high mountains, was covered with the same dense brown and green carpet.

About the shores of Unalaska and for fully 2,000 feet up its rugged

* The tundra of Alaska have been graphically described by the following writers:
John Muir: Botanical Notes on Alaska; in Cruise of the Revenue Steamer Corwin in Alaska and the N. W. Arctic Ocean in 1881. Treasury Department, Washington, 1883, pp. 47-53.
C. L. Hooper: Report of the Cruise of the U. S. Revenue Steamer Thomas Corwin in the Arctic Ocean, 1881. Treasury Department, Washington, 1884, p. 35.
L. M. Turner: Contributions to the Natural History of Alaska. Signal Office, Washington, 1886, pp. 15-16.

mountain slopes the vegetation is essentially the same as at St. Michaels. In climbing the steep slopes about Iliuliuk I often had great assistance from the dense mat of vegetation two or three feet thick, which, clinging to the rocks, converts their angular crags and shattered crests into smooth domes of soft, yielding moss. On the steep slopes, as in the swamps, the vegetation is always water-soaked, owing to the extreme humidity of the climate in which it thrives. Lakelets are common on slopes and hillsides that would be well drained were it not for the spongy nature of their mossy banks.

About St. Michaels and on the delta of the Yukon the tundra is typically developed. The characteristics are the abundance of mosses and lichens and the absence of trees. Cryptogamic plants make more than nine-tenths of its mass. On their power to grow above as they die and decay below depends the existence of the tundra.

The varied vegetation of these moorlands, although seldom more than a few inches high, is exceedingly luxuriant and beautiful. The soft greens and delicate browns of the mosses and lichens make a most artistic setting for the bright blossoms and glowing fruits of the flowering plants. In some localities, usually in sheltered situations near the lakelets, small groves of alders and dwarf willows reach a height of three or four feet, but these exceptions to the usual character of the vegetation are lost to view in the broad treeless expanse.

On bright sunny days, and such days are not uncommon in summer on the usually bleak shores of Alaska, a walk on the mossy fields of the tundra, which at a little distance look like luxuriant pastures, is very enjoyable although exceedingly fatiguing. On wild stormy days, when sleet and snow add to the gloom of a leaden sky, and a cold, piercing wind sweeps in from the sea, the boundless moorlands, without a sign of human existence, are dreary and depressing in the extreme.

Birds inhabit the tundra in great numbers during the summer, and many species, after their long migrations, find there a congenial home in which to rear their young. The bird life of this peculiar region has been studied by W. H. Dall, L. M. Turner, E. W. Nelson, and others, but does not claim our attention at present, as only the geological features of the tundra and of the general mossy covering of Alaska can be considered in these pages.

Mode of Formation.—On making excavations in the tundra, as well as on examining natural sections, I found that the fresh, luxuriant vegetation at the surface changed by insensible gradations to dead and decaying matter a few inches below, and finally became a black, peaty humus, retaining but few indications of its vegetable origin. In an excavation made at St. Michaels on the 13th of July, the tundra was found to be frozen below a depth of eight inches. Where the moss is more open and more luxuriant, the depth to the frozen subsoil was about fourteen inches.

The depth of the humus layer beneath the moss was found to be about two feet at St. Michaels. A mile east of the village it was about twelve feet. In the delta of the Yukon a depth of over fifteen feet was seen at one locality. As satisfactory sections are rare, these measurements do not indicate its average thickness. A depth of 150 to 300 feet has been assigned by several observers to the tundra where it is exposed in a sea-cliff on Eschscholtz bay, at the head of Kotzebue sound. This interesting locality has received more attention than any other similar portion of the shore of Alaska, owing to the fact that the ice is there well exposed and the surface layer of humus is rich in mammalian remains.*

Ice cliffs similar to those in Eschscholtz bay, but of greater extent, occur along the Kowak river, which empties into Kotzebue sound. These ice deposits have been described and illustrated by J. C. Cantwell,† who suggests that they may be the remnant of a frozen river.

The explanation of the formation of the tundra is to be found in the fact that its vegetable covering grows at the surface and dies and decays below, but is frozen before complete decomposition takes place. The surface of the frozen substratum rises as the thickness of the protecting carpet above is increased. There is apparently no reason why this process might not continue indefinitely, so as to store up vegetable matter in a way that is only paralleled in the most extensive coal fields.

A possible Origin of Coal Seams.—So vast is the amount of vegetable matter now imprisoned in the tundra of the North, that I venture to suggest that possibly some coal seams may have had a similar origin.

This suggestion does not seem so very unreasonable when one remembers that except in the circumpolar tundra, deposits of vegetable matter are nowhere accumulating at the present day to anything like the extent or thickness required for the formation of coal-fields like the one, for example, of which Pennsylvania still retains a remnant. Botanists will say at once, in opposition to this suggestion, that the flora of most of our coal-fields, and especially those of Paleozoic age, indicate tropical or sub-tropical conditions.

* Descriptions of this locality may be found in the following books:

Otto von Kotzebue: A voyage of discovery into the South sea and Beering's straits, for the purpose of exploring a northeast passage. Undertaken in the years 1815–1818. London, 1821, 8vo, vol. 1, pp. 219–220.

Captain Beechey: A narrative of the voyage and travels of Captain Beechey, R. N., F. R. S., &c., to the Pacific and Behring's straits; performed in the years 1825, '26, '27, and '28. London, 8vo, pp. 372–377.

W. H. Dall: Extract from a report of C. P. Patterson [On Coast Survey work in Alaska]. Am. Jour. Sci., 3d ser., vol. 21, 1881, pp. 104–111.

C. L. Hooper: Report of the cruise of the U.S. Revenue-steamer Corwin in the Arctic Ocean [in 1880]. Treasury Department, Washington, 1881, 8vo, pp. 24–25.

C. L. Hooper: Report of the cruise of the U. S. Revenue steamer Thomas Corwin, in the Arctic Ocean, 1881. Treasury Department, Washington, 1884, 4to, pp. 79–81. Pl. op. p. 80

W. H. Dall: Glaciation in Alaska. Bull. Philosophical Society of Washington, vol. 6, 1884, pp. 33–36.

† A narrative account of the exploration of the Kowak river, Alaska; in Report of the Cruise of the Revenue Marine Steamer Corwin in the Arctic ocean in the year 1885, by Capt. M. A. Healy, Treasury Department, Washington, 1887, pp. 48-49, and plates op. p. 48.

The flora of the tundra, however, like the plants of the Carboniferous, is essentially and characteristically cryptogamic. Two species of Equisetum, which may be considered as representing the Calamites of former times, flourish with rank luxuriance over great areas along the Yukon.

If the tundra-fringed coast of Alaska should subside, the peaty layer with which it is covered would become buried beneath sands and clays, and form a stratum in every way favorable for transformation into lignite and coal. The plant and animal remains associated with it would indicate the climatic conditions under which it accumulated, but the overlying sandstones and shales might also carry leaves and tree trunks transported by rivers from warmer regions.

Lakes on the Tundra.—The surface of the tundra, as already mentioned, is frequently diversified by ponds and lakelets. Most of these have no definite outlet, but are completely surrounded by luxuriant banks of moss, through which the water escapes as through a sponge. The moss encroaches on the lakelets from all sides, and finally completely covers them in the same manner as the Sphagnum increases about the borders of ponds in the peat bogs of New England and other temperate regions. As the moss covers the lakelets more and more completely during a series of years, the ice formed by the freezing of the water in winter is more and more thoroughly protected, and is finally completely shielded from the heat of summer. A body of clear ice is thus formed in the tundra, similar to the strata of ice exposed at certain localities along the coast of Behring sea and in the banks of the Yukon.

This explanation of the presence of clear ice in the tundra has previously been suggested by L. M. Turner in the introduction to his report on the natural history of Alaska, already referred to. A similar explanation of the presence of thick beds of clear ice in the cliffs bordering Eschscholtz bay has been recorded by E. W. Nelson and C. L. Hooper,* together with an alternative hypothesis to the effect that the ice might have resulted from the freezing of water which filtered through the surface layer of moss.

Stratified Ice in the Tundra.—The great number of lakelets on the surface of the tundra renders it evident that if their extinction and the consequent burial of ice beneath the surface takes place in the manner supposed sheets of ice, probably more or less lenticular in shape, should form a characteristic feature of tundra deposits. The origin of the lakelets may perhaps be due to the accumulation of snow banks on the tundra, which by their late melting enable the moss surrounding them to grow more rapidly than on the more deeply covered areas. In this way a depression in the surface would be formed which would be flooded after the snow melted. A lakelet once

* Report of the Cruise of the U. S. Revenue Steamer Thomas Corwin, in the Arctic Ocean, 1881. By Captain C. L. Hooper. Treasury Department, Washington, 1884, p. 80.

started would perpetuate itself from year to year until the growth of moss from the sides led to its burial. An origin of this nature seems probable, as the lake basins are due entirely to variations in the surface growth of vegetation and not to inequalities of the substratum of rock or clay on which the humus layer of the tundra rests. The origin and extinction of lakelets is thus a part of the normal growth of the frozen moss-covered plains.

MOSSY COVERING OF THE WOODED PORTION OF ALASKA.

Distribution of the Mossy Covering.—The tundra is confined to the vicinity of the coast, where for some reason, probably climatic, trees do not grow. Inland from this belt, however, the mossy covering still continues and occupies a vast area, especially in the lowlands bordering the Yukon and other large rivers. Without exaggeration, it may be stated that the whole of Alaska, excepting the steepest rock slopes and the tops of high mountains, is covered with a dense carpet of moss.

On the flood-plains of the larger rivers, and generally throughout all the lowlands of Alaska, peaty deposits are forming in the same manner as on the tundra, modified, however, by the growth of arborescent vegetation and by the intrusion of sand and clay in places that are flooded during the high-water stage of the rivers.

At many localities along the Yukon sections of peaty deposits are exposed often eight or ten feet thick and several miles long. The bluffs where these layers occur are usually from fifteen to twenty feet high and nearly always frozen solid, except where they are too open in texture to retain water. Some of the vegetable layers are interstratified with sand and clay, as already explained; others at the surface are still increasing in thickness and have a dense forest growing on them. Not infrequently there is a stratum of clear ice interbedded with the layers of peat, sand, and clay.

Depth of the Frozen Stratum beneath the Moss.—The thickness of the frozen substratum beneath the moss-grown forest has never been determined. The deepest excavations that have been made show that it exceeds twenty-five feet.

At Nulato a well has recently been dug near the river bank through clay and sand to the depth just mentioned, in which the material removed was frozen solid, with the exception of certain dry sandy layers. At Forty-mile creek precisely similar conditions have been revealed by mining operations, the depth reached being also about twenty-five feet.

The reason for the great thickness of the frozen layer at these localities seems to be that deposition and freezing went on at the same time. These certainly seem to be the conditions under which the great thickness of frozen material beneath the tundra and in the flood-plains of the larger rivers of

Alaska have been accumulated. It seems to me that this must also be the explanation of the origin of all frozen deposits which contain alternating strata of clear ice and of frozen layers of mud and peat like those exposed in the borders of the tundra and along the banks of the Yukon.

Depth of Frost in the Arctic.—As recorded by K. E. Von Baer,* the ground at Yakutsk, Siberia, is frozen to the depth of 382 feet. It has been assumed by various authors that the great depth of ice in this and other similar instances is due directly to surface temperature, the downward limit to which the winter's cold can penetrate being limited by the internal heat of the earth. Before accepting this explanation as final it should be ascertained whether the strata at the localities where a great depth of frozen material has been encountered might not have been frozen progressively as they were laid down.

Being skeptical as to the influence of the low temperature of northern lands on the strata at a depth of two or three hundred feet below the surface, I consulted R. S. Woodward, of the U. S. Geological Survey, who has kindly furnished the following discussion of the question:

The considerable depth below the earth's surface to which frost or the temperature of freezing is known to penetrate in the Arctic regions, raises the interesting question of the relation between the thermal properties of the earth's crust and the time and depth of penetration. When any portion of the earth's surface is subjected to a temperature differing from that of the crust below, the process of heat diffusion or flow of heat from the warmer to the colder parts of the crust is at once set up. The rate at which this process goes on and the resulting distribution of temperatures will depend, for any given set of temperature conditions, on the conductivity and thermal capacity of the crust. Within such ranges of temperature as we have to consider here the conductivity and thermal capacity of the crust will remain invariable, and they will enter the relation sought as a ratio, which ratio is called diffusivity. With a constant diffusivity, therefore, the form of the relation in question will be determined by the temperature conditions. Of these a variety can be imagined; but a sufficiently definite idea of the nature of the process may be gained by supposing that at the beginning of the time the crust to a depth of a thousand or two thousand feet has a uniform temperature, and that the surface of the crust from and after the initial epoch is maintained at a constant temperature. The maintenance of a constant temperature is practically what results at the surface when a considerable portion of it is covered by

*On the ground ice or frozen soil of Siberia; in Jour. Roy. Geograph. Soc. London, vol. 8, 1838, pp. 210–212.

The presence of perennial ice in the soils and subsoils of northern lands is also treated by the following writers:

Adolph Erman [Note on the depth of frozen strata at Yakutsk]; in Jour. Roy. Geograph. Soc. London, vol. 8, 1838, pp. 212–213.

Adolph Erman: On the temperature of the earth in Siberia; in Jour. Franklin Inst. N. S., vol. 23, 1839, pp. 338–340.

John Richardson: Notice of a few observations which it is desirable to make on the frozen soil of British North America; in Jour. Roy. Geograph. Soc. London, vol. 9, 1839, pp. 117–120.

John Richardson: On the frozen soil of North America; in Edinburgh New Phil. Jour., vol. 30, 1841, pp. 110–123.

Charles Lyell: Principles of Geology. 8th Ed., New York, 1873, pp. 187–188.

C. L. Hooper: Report of the Cruise of the U. S. Revenue Steamer Thomas Corwin in the Arctic Ocean, 1881. Treasury Department, Washington, 1884, p. 80.

a mantle of ice. Under these circumstances the temperature at points in the crust will fall towards that at the surface in a way defined thus:

Let

$u_0 =$ the initial excess of the temperature of the crust over the constant temperature at the surface,

$u =$ the temperature of the crust at a depth x at any time t after the initial epoch,

$a^2 =$ the diffusivity of the crust $= 400$, about (Thomson*), for foot and year as units,

$\pi = 3.1415+$,

$z =$ subject-variable of integration,

$e =$ Naperian base.

Then the fall of temperature $u_0 - u$ is expressed by the equation

$$u_0 - u = u_0 \left(1 - \frac{2}{\sqrt{\pi}} \int_0^{\frac{x}{2a\sqrt{t}}} e^{-z^2}\, dz\right).$$

The following table gives the values of $\frac{u_0 - u}{u_0}$ for various values of the depth x and the time t:

Values of Ratio $\frac{u_0 - u}{u_0}$ for Different Times and Depths.

Depth x.	TIME FROM INITIAL EPOCH.				
	1 year.	25 years.	100 years.	1,000 years.	10,000 years.
Feet.					
40	0.1573	0.7773	0.8875	0.9643	0.9887
80	0.0046	0.5715	0.7773	0.9287	0.9774
120	0.0000	0.3961	0.6714	0.8933	0.9662
160	----------	0.2579	0.5715	0.8580	0.9549
200	----------	0.1573	0.4795	0.8230	0.9436
400	----------	0.0046	0.1573	0.6547	0.8875
800	----------	0.0000	0.0046	0.3711	0.7773
1,200	----------	----------	0.0000	0.1797	0.6714

To illustrate the application of the table, suppose the mean annual temperature over the Alaskan region to have been 10° F. (the present mean annual temperature of northern Alaska) since the initial epoch, and suppose that the temperature of the crust was initially 60° F. Then the u_0 of the formula is 50°. At the end of a year from the initial epoch the temperature at a depth of 40 feet (see table) would fall $0.157 \times 50°$, or about 8°; *i. e.*, the temperature at that depth would be $60° - 8° = 52°$. At the end of 25 years the temperature, at the depth of 40 feet, would fall to about $60° - 0.777 \times 50° = 21°$; but the fall would be hardly perceptible at a depth of 400 feet, etc.

* See Treatise on Natural Philosophy, by Thomson and Tait, Vol. I, Part II, Appendix D.

It appears from the formula and the table that the depths to which any specified fall of temperature penetrates vary inversely as the square roots of the corresponding times.

To find how long a time is required to produce a given fall in temperature at a given depth, we must find t from the preceding equation when all the other factors are known. Thus, suppose that, under the conditions assumed in the above example, we require the time when the temperature will fall to 30° at a depth of 200 feet, the equation becomes:

$$\frac{u_0 - u}{u_0} = \frac{30}{50} = 1 - \frac{2}{\sqrt{\pi}} \int_0^{\frac{200}{40\sqrt{t}}} e^{-z^2}\, dz$$

This gives $t = 180$ years.

The conclusion reached by Mr. Woodward indicates that the freezing of even the deepest ice-stratum reported in the Arctic might have resulted directly from a mean annual temperature no lower than now prevails in northern Alaska. The conductivity of the frozen soils and subsoils of Alaska has not been investigated, but is probably less rapid than in the strata in which the value determined by Thomson and Tait was obtained. Other values may be substituted in the formula, but any probable variations from those used would not affect the general conclusion reached.

Although the passage of heat through the surface layers in Arctic regions is slow, yet it is apparent that the length of time since a mild climate existed there is sufficient, even under existing conditions, to allow of the freezing of strata several hundred feet below the surface. The mean annual temperature of the nonglaciated portion of Alaska during the glacial epoch must have been lower than at present—at least such I am confident would be the conclusion of the majority of geologists,—and there seems good reason for believing that the freezing of the tundra began in Pleistocene time and continued to the present day. An increase in the thickness of the frozen layer, owing to the influence of a mean annual temperature below 32° F. and the deposition of a succession of frozen layers, as suggested elsewhere, may have combined to produce the results now observed.

THE FROZEN MOSS-LAYER AS A GEOLOGICAL AGENT.

Throughout Alaska drainage is obstructed by the universal mossy covering. There is an absence of small streams; rills and even creeks of considerable size are frequently ponded and transformed into swamps by the progressive growth of vegetation from their banks. Not only are the denuding effects of rain-drops falling on the land entirely counteracted by the mossy covering over very large areas, but the water is retained by the spongy moss and allowed to seep slowly away. The streams formed by the water after filtering through the moss are clear and limpid, and consequently unable

to corrade. Their ability to dissolve the rocks with which they come in contact is also greatly reduced by their low temperature. Moreover, the banks of the streams, and even the bottoms of the smaller rivulets, in many instances, are moss-covered, and the soil beneath the moss is frozen. The erosive power of surface water is thus reduced to a minimum. Only the larger creeks and the rivers obey the laws of erosion and of corrasion which are in force in warmer and less humid regions.

Another result of a low mean annual temperature in a humid region is that dead vegetation decays slowly, and prostrate trees and obstructions to drainage formed by drift-wood remain a long time, thus retarding the streams and favoring sedimentation. Many of the smaller drainage valleys of Alaska are impassible on account of the trees that have fallen from either bank and interlaced their branches in the center. Dams are thus formed which favor the increase of swamps. The growth of moss is thus promoted and the difficulties of drainage still farther augmented.

The mossy covering of Alaska decreases in thickness towards the east, and at the head-waters of the Yukon in the North West Territory it is not especially remarkable. In southern Alaska, at least from Juneau southward, the mosses are wonderfully luxuriant, and although not generally frozen, as in the region of the Lower Yukon, they thoroughly protect the subjacent strata.

DECAY OF ROCKS.

Geographical Distribution of Rock Decay.—The prevalence of residual deposits resulting from the atmospheric decay of rocks in warm and humid regions and their decrease in thickness and extent in the colder and more arid portions of the earth's surface has been discussed by me in a previous paper.* At the time the paper referred to was written but little information was available concerning the condition of rock surfaces in high latitudes. What is here presented in this connection may be considered as a supplement to the paper just mentioned and as sustaining in a marked manner the conclusion that rock decay is a function of existing climatic conditions, and in general decreases from tropical to arctic regions.

The conditions for noting the effects of a rigorous climate on rock surfaces are especially favorable in Alaska, for the reason, as will be explained on pages 137–41, that a very large part of our northern territory was not occupied by glaciers during the Pleistocene period. Hence a comparison of the amount of alteration of the rock surfaces there found with the decayed surfaces of similar outcrops in the driftless area of the upper Mississippi valley and in the nonglaciated portion of the Appalachian mountains would reveal

* U. S. Geological Survey, Bulletin No. 52, 1889.

the influence of existing climatic conditions on the decomposition of rocks throughout a wide range of latitude.

Absence of pronounced Rock Decay in Alaska.—The slight alteration that the surface rocks in the nonglaciated region of Alaska have suffered, is shown by their freshness, wherever exposed, and by the total absence of residual clays like those which form such a conspicuous feature of many portions of temperate and tropical countries. Nowhere in Alaska did I see more than a trace of the red and yellow clays which result from the atmospheric decay of a great variety of rocks.

On Unalaska island the evidences of a general glaciation are absent, but a great extension of local ice streams took place during the Pleistocene period, and resulted in the removal of much of the previously accumulated superficial débris. The absence of marked alteration in the surface outcrops and the lack of brilliantly colored clays might, therefore, in this instance be accounted for by glacial action.

My observations were continued at St. Michaels, however, and all the way up the Yukon to the eastern border of the nonglaciated area near the mouth of Big Salmon river, and also for about 200 miles up Porcupine river. Throughout this entire region there is a marked absence of pronounced chemical alteration in the rock surfaces. This statement applies to rocks of many kinds, including limestones, sandstones, granites, and various volcanic rocks. Moreover, there is practically an entire absence of residual clays. The colors one sees in the rocks are usually various tones of gray and brown. The brilliant colors due to oxidation of iron, so prevalent in regions of marked subaërial decay, are absent.

Comparison with other Regions.—Rock decay in tropical countries is known to be great, as has been shown in the memoir already referred to. In the southern Appalachians the brilliantly colored residual clays frequently have a depth of more than a hundred feet over great areas. In the driftless area of the upper Mississippi valley, as shown by Chamberlin and Salisbury,* the residual deposits have an average depth of about seven feet, with a maximum thickness of possibly ten times the average. In the driftless area of Alaska, which extends north of the Arctic circle and probably reaches the Arctic ocean, residual deposits, as already stated, are absent.

Observations in the United States alone thus extend over fully forty degrees of latitude, and prove that rock decay is a direct result of existing climatic conditions. The elements of climate which exert the greatest influence on exposed rock surfaces seem to be temperature and moisture. Rocks decay most rapidly in warm regions, where the rainfall is abundant, and are scarcely at all decayed in arid or frigid regions.

* U. S. Geological Survey, Sixth Ann. Rep., 1884–'85, Washington, 1885, p. 205.

Disintegration of Rocks.

GEOGRAPHICAL DISTRIBUTION OF ROCK DISINTEGRATION.

Observations over very wide areas have shown that while rock decay is most pronounced in warm and moist regions, rock disintegration, accompanied by the formation of talus slopes and alluvial cones, is most energetic in arid regions and in northern latitudes—that is, where great variations of temperature occur. High mountain tops in all lands are especially exposed to the influences which promote rock disintegration.

The general absence of great accumulations of shattered rocks in warm, humid regions is undoubtedly due to a great extent to the rapid decay of rock surfaces, but still the generalization that rocks disintegrate most rapidly in regions where great variation of temperature takes place is abundantly sustained by observation.

In an arid region there is generally a great change in temperature between day and night and between winter and summer, and, besides, both rock decay and stream erosion are retarded. In consequence, subaërial deposits occur in such situations on a scale that is unparalleled in more humid lands.

In high latitudes the great variation in temperature from season to season promotes the disintegration of rock surfaces, while the low mean annual temperature retards decay. The rank vegetation covering large portions of northern countries and the prevalence of frozen soils and subsoils retard erosion and favor the accumulation of débris. Hence the records of rock disintegration on a vast scale are to be expected in all northern regions where recent glaciation has not taken place.

OBSERVATIONS IN ALASKA.

Débris Streams.—Streams of loose, angular débris occur in very many of the high-grade gorges on steep mountain slopes throughout Alaska. These streams of loose stones are especially noticeable on the higher portions of the steep mountain sides along the Yukon. They are lighter-colored than the adjoining moss and lichen covered rocks, owing to the absence of all vegetation upon them. Motion in these streams probably takes place principally during the winter when they are covered with snow, or in the spring when the snow is melting. Many of them are situated where snow accumulates most abundantly, and occasionally originate snow-slides and avalanches; but the downward movement of the débris is probably due principally to the slow settling or "creep" of deep snow on steep slopes.

In the glaciated region of southern Alaska, especially on the steep mountain sides about the head of Lynn canal, streams of stones of the same character as those noticed in the Yukon region are a conspicuous feature in the

wild landscape. Frequently a large débris stream will bifurcate above and be joined by secondary branches, forming a dendritic system of the same general character as that presented by high-grade mountain streams. In fact, the depressions occupied by the débris streams are also lines of water drainage, but the grade being exceedingly steep, they discharge their waters quickly, and are therefore usually dry. Their slopes are usually upwards of thirty degrees, and not infrequently appear to approach the perpendicular. I have observed similar streams of débris on the steep mountains of the Arid Region, but they are there less conspicuous—perhaps on account of the absence of a general covering of moss and lichens on the undisturbed rock surfaces.

Talus Slopes or Screes.—All of the mountains in the nonglaciated portion of Alaska are flanked with great accumulations of angular débris derived from the steep slopes above them. This material forms a pediment about the mountains and accumulates especially in the mouths of steep gorges. Many of the talus slopes are fed by the débris streams just described.

The limestone ranges along the Yukon near the international boundary are particularly noticeable for the magnitude of the talus slopes about them. While enjoying Mr. McGrath's hospitality, I climbed the mountains a few miles north of his station, near Belle Isle, and had a far-reaching view over the surrounding country from an elevation of about 3,000 feet above the river. The crest of the range visited is composed of compact earthy limestone in nearly vertical strata, striking nearly east and west, conformably with the trend of the mountains. This range retains its prominence for fully fifty miles eastward of the national boundary and was in full view while subsequently journeying up the Yukon. Its crest is composed of blade-like crags of rock forming an exceedingly sharp crest line, flanked by vast slopes of loose angular stones on either side. The rock is fresh and undecomposed, but everywhere shattered and fissured. The upper portions of the talus slopes, like the crags rising above them, are bare of vegetation. At a lower level they are covered with moss, increasing in thickness as one descends, and finally, at an elevation of about 2,000 feet above the river, merging with the nearly universal forest covering of the country.

The conditions just described prevail throughout the nonglaciated portions of Alaska and the North West Territory, but not in the recently glaciated area of the upper Yukon region.

Absence of Débris in the Glaciated Region.—In the glaciated region drained by the Lewes, and also throughout southern Alaska, there is a remarkable absence of débris on the mountains. It is evident that the ice movement in this region swept the surface clear of previously accumulated fragmental material. On the south side of the Coast mountains the débris carried away by the ice was deposited in the ocean; on the north side the ice movement was

a little west of north and the glaciers ended before reaching the sea. Where these glaciers deposited their morainal material has not been determined.

The débris streams and accompanying talus slopes on the steep mountains about Lynn canal, mentioned on page 135, record the amount of disintegration that has taken place since the retreat of the ancient glaciers.

Amount of Disintegration.—It is difficult to even roughly estimate the amount of disintegrated rock about the bases of the mountains of Alaska, or to compare it with similar accumulations elsewhere. It is my judgment, however, based upon personal observations, that the extent to which the rocks of Alaska have been disintegrated is greater than that of the mountains of Colorado or of the southern Appalachians, but less than that of the Great Basin region. The vast alluvial cones of Nevada and southeastern California are unrivalled by anything of a similar nature that fell under my notice in Alaska.

Glaciation.

PREVIOUS EXPLORATIONS.

The Yukon region from St. Michaels to Fort Yukon was examined by W. H. Dall* in 1867. In the brief published account of the geological results of this exploration it is stated that there is an absence of all evidence of glaciation in the country examined. In a later publication Dall † remarks on the absence of glacial records on the west coast of Alaska north of St. Michaels, and states that the absence of bowlders in that region had been previously noted by Franklin and Beechey.

In 1881 John Muir accompanied the revenue steamer "Thomas Corwin" during her voyage to Behring sea and the Arctic ocean, touching at Unalaska and at several points on the west coast of Alaska, besides skirting the Siberian coast from the Gulf of Anadyr to North cape. He also visited several of the islands in Behring sea and the Arctic ocean. The geological results of this voyage are presented in a paper "On the glaciation of the Arctic and sub-Arctic region visited by the U. S. Steamer Corwin in the year 1881."‡

In this report it is claimed that sufficient proof is presented to show that the entire Behring sea region was occupied by a vast continental glacier during the glacial epoch, and that the ice flowed southward across the Aleutian islands and discharged into the Pacific ocean. I have examined two of the localities visited by Muir, as elsewhere stated, and at each of them I looked for and failed to find any evidence to sustain his generalization.

* Am. Jour. Sci., 2nd Ser., Vol. 45, 1868, p. 99. See also Observations on the Geology of Alaska, in Coast Pilot of Alaska, First part, by George Davidson. U. S. Coast Survey, Washington, 1869, pp. 195-196.

† Bull. Philosophical Soc. of Washington, Vol. 6, 1884, p. 34.

‡ In report of the cruise of the U. S. Revenue Steamer Thomas Corwin in the Arctic Ocean, 1881, by Capt. C. L. Hooper. Treasury Department, Washington, 1884, pp. 135-147.

Dawson's report on an exploration in the Yukon district contains a description of the country traversed by me from the mouth of Pelly river to Juneau, as already stated. Dawson reports an absence of glacial records along the Yukon (Pelly) below the mouth of Big Salmon river, and their presence higher up in the same drainage system.

McConnell's observations on the glaciation of this region have already been referred to. His conclusions were that there are no records of glaciation along the Porcupine or along the Yukon below the neighborhood of the mouth of Big Salmon river, but above that locality there are abundant records of a northward flowing ice sheet, as had been determined by Dawson.

The conclusions of Dawson and McConnell agree in all essential particulars, and demonstrate that there is a great area to the north of the northern limit of the Cordilleran glacier, as named by Dawson, which was not occupied by ice during the Pleistocene.

My own conclusions accord with those just referred to. The central and northern parts of Alaska, like a large portion of the North West Territory, was not, in my opinion, occupied by ice in recent geological times.

PERSONAL OBSERVATIONS.

Unalaska.—While at Iliuliuk I examined the neighboring region, and looked especially for evidences of former glaciation. In this search I was unsuccessful. I found neither glaciated surfaces, perched bowlders, moraines, bowlder clays, nor any of the well-known records of ice action. The rugged topography of Unalaska and neighboring islands is sufficient to show that this portion of the Aleutian chain has not been abraded by a great ice sheet.

In sailing along the shores of Unalaska and neighboring islands one sees round-bottomed valleys opening to the sea. These valleys have the characteristic cross-profile of glaciated troughs. On some of the higher peaks there are cirques similar in every way to those so common about summits that have been centres of ice accumulation. I examined one of these cirques on the north side of Mount Wood,* some four miles south of Iliuliuk, and at a height of about 2,000 feet, but found no evidence of excavation by glacial ice. The cirque was partially filled with snow at the time, and this may have concealed striated rock surfaces and moraines visible later in the season.

The presence of glaciers on the side of Mount Makooshin (Makushin), the highest peak on the island, reported by T. A. Blake,† together with the indication of former local ice streams furnished by the U-shaped cañons and the cirques just mentioned, suggest that local glaciers of large size, but of the Alpine type, radiated from Unalaska during the glacial epoch.

* Designated as "Pyramid Mt. Peak" on U. S. Coast Survey Chart of Captain's Bay, 1875.

† Report upon the Geology of Alaska; in Ex. Doc. No. 177, 40th Congress, 2d session, House of Representatives, Washington, 1868, pp. 314–325.

There is an interesting feature in the contour of the mountains forming the most conspicuous portion of Amaknak island, which may have some connection with former glaciation. The lower slopes have a rounded and flowing outline, due in part to their mossy covering, which is limited in the upper portion of the mountain by an irregular scarp. Above the scarp the mountain slopes are steeper and more angular than below. It may be that the scarp referred to marks the upper limit of former glaciation. Another suggestion is that it is an ancient sea-cliff. This record and suggestion is made with the hope that some one having opportunity may be stimulated to investigate the phenomena more fully.*

From the summit of Mount Wood, mentioned above, a magnificent view can be had on clear days of one of the most rugged landscapes that can well be imagined. The impression that one receives from such a wide-reaching view of Unalaska is that its topography is without system. The more one studies the forms of the land the stronger this impression becomes. The island is without the orderly arrangement of valleys usually so characteristic of well-drained districts in humid regions. There are bold cliffs and outstanding buttes which bear evidence of orographic disturbances and of long exposure. I was not able to detect any evidence in the relief of the land of the former presence of a general ice sheet, nor was I more successful in attempting to trace the paths of ancient Alpine glaciers. The topography of the island is chaotic. Ragged cliffs, shattered peaks, together with walls and spires of naked rock, rise on every hand, but without orderly arrangement.

I suspect that the reason for the confused and exceptional character of the topography is due in large part to the obstruction offered to erosion by the mossy covering of the lower portions of the island. The rain that falls in the region of the Aleutian islands and in Alaska generally partakes of the character of "Scotch mists" rather than of tropical down-pours. This and the fact that a very large part of the annual precipitation is in the form of snow would indicate that the impact of rain drops, an important factor in the erosion of many regions, is here reduced to a minimum.

From Mount Wood one sees the majestic snow-clad summit of Makooshin against the western sky. Across Akutan pass, to the east, is another active volcanic cone of surprising beauty, rising above the sea mist like a cone of burnished silver far into the clear heavens. To the north of Captain's harbor is the extinct volcanic crater known as Paistrakov, the sides of which have scarcely been scored by erosion. These mountains, formed by volcanic

* It may be well in this connection to direct attention to certain obscure indications of terraces or sea-cliffs, at an elevation of fifteen hundred or two thousand feet, on a number of the mountains near the Yukon, below Nulato. None of these mountains have been closely examined, and it is impossible to state whether the indefinite lines which may indicate terraces are horizontal, or whether they coincide in elevation. It is not safe to assume that they are terraces, as it is possible that they may indicate lines of structure or be due to land slides. The mountains are so situated that they could not have retained a lake, and if water lines exist on them their origin must be looked for in a submergence of the land.

extrusion, are the only ones that seem familiar to my eyes in the Unalaska landscape.

Many pages might be devoted to describing the scenery of this region, and especially the magnificent cliffs overlooking the sea, but my visit was too hasty to admit of such study as this subject demands.

The characteristics of the scenery about Iliuliuk, as it appears to an observer on Mount Wood, have been graphically described by H. W. Elliott.*

"Turning right about and looking south, our eyes fall upon a radically different landscape—a bewildering, labyrinthian maze of Oonalashkan mountain peaks and ranges, rising in defiance to all law and order of position, with that lovely island-studded water of the head to Captain's harbor in the foreground. Ridge after ridge-summit after summit, fades out one behind the other into the oblivion of distance, where the suggestion of a continuance to this same wild interior is vividly made, in spite of wreaths of fog and lines of snowy sheen, relieved so brightly by that greenish-blue of the mosses and sphagnum in which they are set. A few pretty snow-buntings flutter over the rocks to the leeward of our position; their white, restless forms are the only evidence or indication of animal life in our rugged vista of an Oonalashkan interior."

To my mind it is plain that the scenery described by Elliott is incompatible with Muir's hypothesis of a former ice sheet flowing southward over the Aleutian islands.

Absence of Glacial Records about St. Michaels.—The region about St. Michaels is so completely buried beneath tundra deposits that opportunities for observing glacial records, if any exist, are rare. The stratum of blue clay beneath the humus layer of the tundra, however, mentioned on page —, shows no evidence of glacial origin. The volcanic craters near at hand which rise above the tundra still retain their characteristic forms, and are without striation, perched bowlders, or other evidences of glacial action.

Absence of Glacial Records along the Yukon.—During the voyage up the Yukon I looked attentively for evidences of glaciation, but saw no indication of a former occupation of that region by ice until after passing the mouth of Little Salmon river, in the North West Territory, approximately in latitude 62° N. Along the Yukon and the Lewes above this locality there are abundant records of the former presence of a northward flowing ice sheet. The limit of the nonglaciated region on the Yukon has not been definitely determined, but provisionally it may be taken as stated above.

Along the Yukon from its mouth to where it is joined by the Little Salmon, a distance of about 1,500 miles, there is an absence of striated rock surfaces, "perched bowlders", bowlder clay, moraines, and all other evidence of an ice invasion. This negative evidence is corroborated by the presence, along the river bluffs and on the mountains, of numerous pinnacles and spires due to long-continued subaërial erosion, and by vast talus slopes about the steeper

*Our Arctic Province. New York, 1887, p. 163.

escarpments, which, as shown by the nearly complete removal of such material in the region occupied by the Cordilleran glacier, could not have retained their characteristic shapes had they been subjected to glacial action.

Not only is there proof of the absence of a general ice sheet over the greater part of the extensive region indicated above, but the mountains seen from the Yukon, several of which are fully 4,000 feet in elevation, are without evidence of local glaciation. There are no cirques about their summits or wide cañons with lateral or terminal moraines on their sides. All of the mountains here referred to are near, and some of them are north of, the Arctic circle, yet they are now completely bare of snow throughout the summer. This indicates that existing climatic conditions are analogous to those prevailing in the same region during the glacial epoch.

Absence of Glacial Records along the Porcupine.—I saw no evidence of glaciation along Porcupine river, and my observations in this matter agree with McConnell's. At the highest point reached by me on the Porcupine the hill-tops, having an elevation of about 400 feet above the river, were covered with well-worn gravel. These are probably stream gravels, and correspond to the high terraces observed in the upper portion of the Yukon and along the Lewes.

The Snow Line.—It is stated in many works on geography that the lower limit of perennial snow occurs at an elevation of about 18,000 feet in the tropics, decreases in elevation towards the north and south, and reaches sea level in the antarctic and arctic regions. Alaska and the North West Territory offer marked exceptions to this supposed rule. The snow line in southern Alaska is at an elevation of about 3,000 feet, and increases in height towards the north. John Muir * says—

"There is no line of perpetual snow on any portion of the arctic region known to explorers. The snow disappears every summer not only from the low sandy shores and boggy tundras but also from the tops of the mountains and all the upper slopes and valleys with the exception of small patches of drifts and avalanche-heaps hardly noticeable in general views. But though nowhere excessively deep or permanent, the snow-mantle is universal during winter, and the plants are solidly frozen and buried for nearly three-fourths of the year."

GLACIATION IN THE UPPER YUKON REGION.

Previous Explorations.—The glaciation of the region drained by the head-waters of the Yukon has been described by Dawson and McConnell, as already stated.

The records of ice action in this region are smoothed, polished, and striated rock surfaces, perched bowlders, and deposits of bowlder clay. Distinct and well-defined moraines have not been observed, and the country generally is

* Botanical Notes on Alaska, in Cruise of the Revenue-Steamer Corwin in Alaska and the N. W. Arctic Ocean in 1881. Treasury Department, Washington, 1883, p. 47.

remarkably free from loose material of any kind, except in the bottoms of the valleys, where stream-borne gravels, river terraces, and lacustral silts are abundant.

It does not seem desirable to describe the glacial phenomena of this region in detail, since this would necessitate a repetition of what has been recorded in many other similar areas. Brief notice of some of the most interesting features due to ice action, however, may not be out of place.

Upward Deflection of Glacial Grooves.—On the east side of Lake Lebarge there is a conspicuous range of rounded limestone domes, known as the Hancock hills, which have an approximate elevation of six or eight hundred feet above the lake. These hills have been intensely glaciated, especially on their southern sides. Their northern slopes are broken and rugged, showing unmistakably the direction of movement of the ancient ice sheet which remodeled their forms. On the nearly vertical precipices overlooking the lake there are, at one locality, strongly drawn grooves, which ascend slightly towards the north—that is, in the direction of ice movement. The upward tending of the lines amounts, perhaps, to two or three degrees. The cause of their abnormal course was a projection or shoulder on the face of the cliff, at right angles to its general course and also at right angles to the direction of ice movement, which acted as a dam to the ice current and caused it to rise in order to pass the obstruction. Stones set in the side of the glacier moved with the ice and left a record of their course on the cliff against which they were pressed.*

Freshness of the Glacial Records.—The Hancock hills are bare of débris, excepting an occasional perched bowlder, and, what is more important, are so steep and smooth that they must have been uncovered and exposed to the atmosphere ever since the ice left them. The surfaces of vertical walls, and even the summits of the rounded domes, still retain the grooves and scratches made by the ancient glacier. The surface polish of the limestone has disappeared from the more exposed situations, but disintegration has not progressed far enough to obliterate, or even to greatly obscure, the ice markings.

When we consider the severity of the climate to which these hills have been exposed, the freshness of the glacial records upon them is significant as indicating the recent date of the glacial epoch. The rate at which the surfaces of similar rocks are known to crumble and decay in temperate latitudes seems to indicate that the more exposed portions of the Hancock hills could not retain their glacial markings more than a few hundred years. Apparently the glaciation of the region about Lake Lebarge occurred hundreds, but not thousands, of years ago.

*Ascending and descending striæ on vertical rock surfaces similar to those just noticed have been described by T. C. Chamberlin as occurring in New York and Ohio. Seventh Ann. Rep. U. S. Geol. Survey, 1885–'86. Washington, 1888, pp. 171–173.

The freshness of glaciated surfaces in the North West Territory, in southern Alaska, and in the High Sierra of California merits attention. It may be suggested in this connection that the glaciers on the west coast of North America were not contemporaneous with the Pleistocene glaciation of the northeastern part of this continent, but of much later date.

Bowlder Clay.—In the valley of the Yukon, between Rink rapids and Lake Lebarge, there is a deposit of bowlder clay some twenty-five to thirty feet thick, exposed in the scarps of the terraces bordering the river. That this is a true bowlder clay deposited by glaciers is accepted without question by both Dawson and McConnell. It is a light-brown earthy deposit, quite homogeneous in composition, but sometimes obscurely stratified, and contains pebbles and bowlders, some of them striated, scattered abundantly through it. It occurs just below a region that bears undisputable evidence of ice occupation, and has unquestionably the characteristics of a true glacial deposit. To doubt that it was deposited directly by glaciers may seem hypercritical; but there are good reasons for believing that a very similar deposit is now forming in the Yukon and other northern rivers, owing to the transportation and deposition of gravel and bowlders by river ice.

The bowlder clay along the Yukon is apparently confined to the river valley and does not cover the adjacent hills. At least I could not satisfy myself that it extends back from the river, as would be expected had it been deposited by a broad ice sheet. The bowlder clay along the Yukon occurs only below Lake Lebarge. Above that lake the lacustral deposits, which are a continuation of these resting on the bowlder clay lower down stream, have been dissected by the river to a depth of 150 feet or more, and in some places, as at Miles cañon, to the underlying rock without exposing a substratum of bowlder clay. As this region bears evidence of intense glaciation, it is to be expected that a bowlder clay should occur there also, if the deposit lower down stream is directly of glacial origin.

The deposition of bowlder clay by northern rivers is referred to on page 120 of this paper, where the agency of ice in modifying river deposits is discussed.

Direction of Ice Movement.—It has been determined by Dawson that the main direction of ice movement in the upper Yukon region was about N. 8° W.* Local deflections conforming to the trend of the larger valleys have been observed.

During my journey from Lake Lebarge to the summit of Chilkoot pass abundant opportunity was offered to verify Dawson's conclusions. On crossing Chilkoot pass, and subsequently while traversing Lynn canal and the "Inland Passage" south of Juneau, the general direction of former ice move-

* Rep. Yukon District, loc. cit., 1887, p. 159B.

ment was observed to be southward, as has been stated by several other travelers. The coast range of Alaska was therefore a center of ice accumulation during the Glacial epoch.

Northern Limit of Glaciation.—The most northern locality at which glacial furrows have been observed along the Yukon is about a mile below the mouth of the Lewes. Bowlder clay occurs some sixty or seventy miles lower down the river and, if of true glacial origin, indicates that the northern limit of the ancient glacier must have been approximately a little north of latitude 62°. This is the limit assigned by McConnell. More detailed investigation is needed, however, before the extent of the ancient glacier can be definitely assigned. No terminal moraines marking the extent of the ice invasion have been reported, and we are still ignorant of the disposition of the immense amount of débris that was removed from the glaciated area. Neither has a division of the period of glaciation been recognized.

Terraces.

Stream Terraces along the Yukon.—The first terrace observed in ascending the Yukon is on the right bank of the river, about thirty miles below Anvik. At that locality there is a nearly perpendicular escarpment about fifty feet high, formed of sand and well-rounded stones that have been deposited against the steep mountain side. The surface of the gravel deposit forms a shelf which may be traced for a mile or more.

Terraces along this part of the river are not common, owing, apparently, to their having been removed by the erosion of the stream. Above Anvik they become more and more frequent, but do not form a conspicuous feature in the landscape until after passing the mouth of the Porcupine and approaching the international boundary.

Opposite McGrath's station, near the international boundary, the elevation of the highest terrace was determined by angulation to be 734 feet above the river. The terrace at this point is not strongly defined, but that it is a river terrace seemed to me certain. Its elevation seems greater, however, than the highest terraces seen either above or below the 141st meridian.

From the boundary all the way up the Yukon to the mouth of the Lewes, and up the Lewes to Lake Lindemann, terraces are not only conspicuous but form an important element in the scenery of the region.

The terraces here referred to are of two types: (1) lake terraces, described a few pages in advance; and (2) stream terraces. The stream terraces are again separable into two groups, (*a*) rock-cut terraces and (*b*) gravel terraces.

Rock-cut terraces are not common along the Yukon, yet a few conspicuous examples were observed. Their surfaces are usually covered with riverborne gravels, so that in some cases their true genesis is obscure. A

characteristic example of a rock-cut terrace occurs a few miles below the international boundary. The rock is there a contorted slate and rises steeply to an elevation of about 150 feet, where a broad terrace occurs, the surface of which is covered by twenty to thirty feet of gravel. Back of the terrace the mountain rises precipitously to a height of several hundred feet. This and other terraces of a similar character in the same general region show that the Yukon at one time flowed in a comparatively broad valley, and spread out characteristic flood-plain deposits. Subsequently it deepened its channel and left portions of the bottom of its former rock-cut trough in the form of a terrace on the mountain side.

Most of the terraces of the Yukon are of gravel, and show that a previously eroded valley was deeply filled with stream-borne material, and that subsequently, owing to increased grade, or perhaps to a lessening of load, the stream eroded a new channel, leaving portions of its flood-plain from time to time as terraces along its borders. In places from five to six terraces may be easily recognized, and not infrequently followed continuously for many miles. Where they have been cut away on one side of the valley, they almost invariably appear on the opposite side. No opportunity was afforded, however, for examining them in detail. The most interesting contribution that I am enabled to offer concerning them is their increase in elevation as one ascends the Yukon. From about fifty feet in height above the river near Anvik, they increase to over 700 feet at the international boundary. Above the boundary the highest terrace is, by estimate, about 400 feet above the river.

Volcanic Dust in Stream Terraces.—The scarps formed by the cutting away of gravel terraces along the Yukon near the mouth of Pelly river, and at many localities on the Lewes, exhibit a conspicuous white band, formed by a stratum of volcanic dust from eight to twelve inches thick, which was blown out of some volcano with great violence at a recent date, and deposited over a very wide belt of country. This deposit has been described by Dawson * and was also noticed by Schwatka. †

I was informed by Arthur Harper, one of the most observing and obliging traders on the Yukon, that a stratum of material similar to the one in the banks of the Yukon below the mouth of Pelly river was seen by him at Belle Isle, and also at Fort Yukon. Frank Densmore, one of the most experienced frontiersmen of Alaska, reports a similar deposit in the valley of the Tenanah, some 200 miles above its mouth. These observations indicate that the bed of volcanic dust, so conspicuously exposed along the upper Yukon and the Lewes, occupies a belt of country fully 500 miles broad from east to west.

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* Rep. Yukon District, loc. cit., pp. 43B–46B.
† Along Alaska's Great River. New York, 1885, p. 196.

Among the numerous problems awaiting examination by observant travelers in Alaska is the determination of the extent and source of this deposit.

Plateau Terraces.—The level-topped bluff known as the "Palisades," below the mouth of the Tananah, has already been mentioned. The strata forming these bluffs have every appearance of being lacustral sediments. The erosion of a stream channel across the level plain formed by the bottom of the old lake has left portions of it in the form of a broad terrace, bounded on one side by the steep river bank and on the opposite side by encircling hills. This terrace appears level, but it is not a lake terrace as that term is usually understood, neither is it a stream terrace; for convenience it may be termed a *plateau terrace.* At the mouth of Pelly river a broad, nearly level lava coulée has been cut by the Yukon and by the Pelly, and forms another example of this kind of terrace.

The Lewes between lakes Lebarge and Marsh has excavated a deep channel across a plain formed of the sediment of a post-glacial lake, described below under the name of Lake Yukon, and has left a broad level area on each side of its course similar in every way to the terrace of older date at the Palisades.

Examples of plateau terraces are common in many other regions, and the name here proposed may be found sufficiently convenient for adoption by geologists and geographers who study the origin of topographic forms.

Lake Terraces.—Horizontal terraces occur all about the borders of the lakes drained by the Lewes, at various elevations up to several hundred feet. These water lines were formed by an ancient lake which has now passed away; or perhaps more correctly, has been drained sufficiently to become divided into a number of independent water bodies, of which lakes Lebarge, Marsh, Tagish, and Bennett are the best-known examples.

As the ancient lake here referred to will doubtless receive attention in the future, I have proposed to name it after the river which drained it.

LAKE YUKON.

Previous Observations.—Numerous observations concerning the terraces and sediments of Lake Yukon may be found in Dawson's report of a reconnoissance in the Yukon district.* The terraces were also noticed by Schwatka while descending the Lewes in 1883.†

Position and Extent.—The first evidence of the former existence of an ancient lake on the head-waters of the Yukon which one meets in ascending that river, is in the neighborhood of the mouth of Little Salmon river. Thence up-stream to the mouth of the Lewes, and up the Lewes to Lake

* Loc. cit., pp. 149B, 151B, 154B, 159B, 162B, 163B.
† Along Alaska's Great River. New York, 1885, p. 111.

Lindemann, either the terraces or the sediments of the old lake are constantly in sight. The lake probably extended far up the Yukon above the mouth of the Lewes, and perhaps occupied the valley about Teslin lake; but this region is as yet unexplored. It occupied the valley in which Lake Lebarge is situated, and also filled Ogilvie and Richthofen valleys which open from it on the west. It also extended some distance up the valley of Tahk-heena river. Above Lake Lebarge it formed an extremely irregular water body, which filled the valleys now occupied in part by lakes Marsh, Tagish, Bennett, and Lindemann. An extension eastward into the long, narrow valley of Atlin lake is suspected, but has not been proven by observation.

As will be seen from this brief description, Lake Yukon was extremely irregular. It occupied a number of long, narrow valleys which chanced to be connected and so situated as to be flooded by a single lake, having a depth in the valley of Lake Lebarge of between five and six hundred feet.

From north to south, Lake Yukon was about 150 miles long. Its width near Miles cañon and in the valley of Lake Marsh was about ten miles. In other valleys it was much narrower, and even at its highest stage must have appeared as a broad, placid river. Its extent, as well as the date of its existence places it among the more important lakes which were formed at various localities on this continent during or immediately following the glacial epoch. Of these, the best known at present are lakes Agassiz, Bonneville, and Lahontan.

Depth as shown by Terraces.—The highest of the horizontal water lines above Lake Lebarge has been estimated by Dawson* to have an elevation of 400 feet above the surface of the existing lake. My own estimates make its elevation about 150 or 200 feet higher. The elevation of the surface of Lake Yukon above the sea during its maximum expansion must, therefore, have been between 2,500 and 2,700 feet; the elevation of Lake Bennett being taken at 2,150 as determined by Dawson.

Sediments.—The fine, light-colored, horizontally stratified sediments of Lake Yukon are well exposed in the steep river bluffs and along the lake shores, all the way from near the mouth of Little Salmon river to Lake Bennett. Fine exposures fully two hundred feet thick are to be seen along the Lewes between lakes Lebarge and Marsh. At Miles cañon the lake beds rest on a floor of lava which is now being cut by the stream. The channel occupied by the river previous to the existence of the old lake was re-occupied only in part after the lake was drained and a new channel excavated. There is here a fine example of superimposed drainage.

Origin of the Lake.—The position of the outlet of Lake Yukon is as yet uncertain. What held its waters in check also remains to be determined.

* Report on the Yukon District, loc. cit., p. 159B.

Several explanations of the origin of the lake may be suggested, but each requires additional field observations in order to prove or disprove it.

The first and least probable of these hypotheses is that the drainage of the Yukon was obstructed and dammed by the large lava flow at the mouth of the Pelly, along the border of which the river has excavated a recent channel.

Another possible explanation is that moraines were deposited about the northern border of the Cordilleran glacier, obstructing the drainage and giving origin to the lake when the glacial ice was melted. This supposition finds some support in the approximate coincidence of the northern limit of glaciation with the northern extension of the old lake.

Still another hypothesis is that the weight of ice forming the great Cordilleran glacier was sufficient to depress the earth's crust in the manner suggested by students of glaciation in other regions. As the ice retreated, the depression thus originated was occupied by a lake, which was slowly drained as the channel of discharge was deepened or as the land regained its former elevation. The observed increase in the elevation of the terraces of the Yukon from mouth to source seems to be a direct and important confirmation of this hypothesis.

Existing Glaciers.

Observations at Chilkoot Pass and about Lynn Canal.—In describing the nonglaciated condition of the Yukon region, it was mentioned that all mountains in that region are now bare of snow in summer, and hence are without glaciers. Snow was absent from all mountains seen during my journey up the Yukon and Lewes until reaching Lake Bennett, when the Coast Range of southern Alaska came in sight.

In crossing Chilkoot pass I saw five or six small glaciers on the north slope of the range. Some of them were in cirques; others on the sides of the more lofty mountain spires along the crest of the range. Their lower limit appeared to be about 3,000 feet above the sea. About Crater lake, snowbanks and some ice on the steep mountain side extended down to the very margin of the water. These accumulations, however, did not have the characteristics of true glaciers. Crater lake occupies the bottom of an immense amphitheatre, which was the source of a large glacier during quite recent times. The records of ice action are to be seen everywhere about the lake and in the wild valley leading from it towards Lake Lindemann. It is evident that a slight change of climatic conditions, favorable to the accumulation of snow, would reproduce the counterpart of the ancient glacier which once flowed from the amphitheatre of Crater lake.

The weather was thick and extremely unfavorable for observation during my journey from Lake Lindemann to Lynn canal. The only observations

of interest made during this portion of the trip were on the small size of the glaciers on the north sides of the mountains in comparison with the great extent of the ice fields on their southern slopes; on the general absence of débris from the surfaces of the ice streams on each side of the range, and on the absence of conspicuous moraines from their sides and extremities.

In descending from Chilkoot pass to the head of Lynn canal, several small glaciers were seen on either side of the deep cañon-like valley through which the Taiya river flows. The muddy condition of the streams tributary to the main drainage line indicated that there were other glaciers on the mountain above, which could not be seen from the bottom of the valley.

The glaciers seen on the precipitous sides of the Taiya valley present considerable diversity. Some of them are in gorges and lateral valleys, but others are on exposed slopes and form conspicuous prominences in the contour of the mountain when seen from below. Some of them contract gradually toward their lower extremities and end in tapering tongues of ice; others expand and form fan-shaped termini, after the manner of the Rhone glacier; some of them have ice caves at their extremities, from which torrents of turbid water rush down the rocky slope below; others melt away without forming these beautiful blue grottoes. As the glaciers are remarkably free from débris and have but slight morainal accumulations about them, the variety they present near their lower extremities must be due mainly to the relief of the cliffs and mountain slopes about them; yet it is difficult to trace any connection between their diverse forms and their environment.

From a mountain top about 3,000 feet high, on the west side of the valley near the mouth of Taiya river, I obtained an extensive and most interesting view of the extremely rugged country about the head of Lynn canal. The glaciers in this region are small in comparison with those reported by various travelers as existing on the seaward slope of the St. Elias range, but they present great diversity, and some of them are several miles in length. The more elevated portions of the mountains seen from my station, with the exception of the more precipitous peaks and crests, were covered with snow and ice and gave rise to a large number of ice streams. From one station I counted nearly forty veritable glaciers; a change of position of half a mile brought others into view which before were concealed by the rugged crags and snow-covered slopes near at hand. The outlines of vast amphitheatres could be traced by lines of crags along their borders, but the depressions themselves were filled nearly to the brim with ice. The ruggedness of these great basins in the summits of the range, was so completely concealed that a person could walk with ease from peak to peak across an ice-field where a passage would be impossible should the ice be melted.

The present condition of the mountains of southern Alaska presents a

graphic picture of what must have existed in the Sierra Nevada and some other similar ranges during the Glacial epoch. A careful study of what is now taking place in these ice-covered mountains would no doubt go far toward explaining many of the records of glaciation found in regions where glaciers do not now exist.

The glaciers seen about the head of Lynn canal, like those on the sides of the valley of the Taiya, present great variety. Some of the larger amphitheatres are drained by veritable rivers of ice several miles in length, which receive tributaries from neighboring slopes and lateral cañons. Many of the ice masses, especially those in the smaller cirques, are not drained by well-defined ice streams, but like the secondary glaciers of the Alps, described by Forbes, and the existing glaciers of the High Sierra of California, form tongues of ice which have all the characteristics of the larger glaciers, excepting that topographic conditions limit their growth.

In some instances secondary glaciers of considerable size occur on steep mountain slopes, without any indication of an amphitheatre or depression beneath them. These ice bodies frequently appear as convexities on the mountain side, fully exposed to the sky on all sides. Many of the névé fields about Lynn canal, as is common in all ice-covered mountains, are drained by several glaciers. The ice streams flowing from snow-fields near the crest of the mountains in some instances drain both north and south, and contribute on melting both to Taiya river, which reaches the sea within half a dozen miles, and to the Yukon, the mouth of which is two thousand miles away.

Above the snow-fields there are many spires and minarets of shattered rock which bear no evidence of ice abrasion. These bold pinnacles occur especially along the rims of ice-filled amphitheatres, and are the most prominent where the walls of two or more depressions unite. The spires projecting above the névé are frequently so slim and tapering that they look like tree trunks when viewed from the valleys below. The angular and unabraded condition of the extreme summits of these mountains agrees with what may be seen about the more lofty summits of the High Sierra, and illustrates still farther what must have been the condition of that picturesque region at the time it was shrouded in glacial ice.

One of the most striking features of the high, ice covered region of southern Alaska is furnished by the clouds and vapor-wreaths that nearly always encircle the mountains, or rise miles in height above them. Even on bright sunny days, when the sky is clear and blue, the moisture borne upwards by the warm air rising from the valleys is condensed and forms cloud-masses, which roll upwards with fleecy whiteness like thunder-caps in temperate latitudes. The ever-changing forms of these vapor-wreaths and the blue shadows they cast on the snow impart a suggestion of life and motion to the

frozen landscape, the charm of which is beyond description. All of the higher summits and ice-bound plateaus are above the upper limit of tree growth, but the ice streams descend far into the forested region, and many of the larger glaciers end in dense groves of spruce and hemlock.

In the valley of the Taiya the timber line is sharply drawn along the bordering cliffs at an elevation of about twenty-five hundred feet. Above that height the mountain sides are stern and rugged; below is a dense forest of gigantic hemlocks, festooned with long streamers of moss, which grows even more luxuriantly than on the oaks of Florida. The ground beneath the trees and the fallen monarchs of the forest are densely covered with a soft, feathery carpet of mosses, lichens, and ferns of all possible tints of brown and green. The day I traversed this enchanted valley was bright and sunny in the upper regions, but the valley was filled with drifting vapor. At one minute nothing would be visible but the somber forest through which the white mist was hurrying; and the next, the veil would be swept aside, revealing with startling distinctness the towering mountain spires, snowy pinnacles, and turquoise cliffs of ice towering heavenward. These views through the cloud rifts seemed glimpses of another world. Below was a sea of surging branches that filled all the valley bottom and dashed high on the bordering cliffs. Much space could be occupied with descriptions of the magnificent scenery about Lynn canal, and of the wonderful atmospheric effects to be seen there; but the poetry of travel is foreign to these pages, and must be left for more facile pens.

Absence of Débris on the Glaciers.—One of the most noticeable features of the glaciers about Lynn canal, and, in fact, of all of the glaciers that I have seen in Alaska, is their general freedom from débris and the small size of the moraines that are being formed about them. At times faint medial moraines may be seen upon them, especially when viewed from a distance; but in all cases these are composed of small stones and dirt, and do not contribute to the formation of conspicuous terminals at the extremities of the glaciers.

The glaciers about Lynn canal are without the convexity of surface so pronounced in many Swiss glaciers. This is seemingly accounted for by the fact that they are remarkably free from débris, and hence equally exposed in all parts to the heat of the sun. In some instances, where the glaciers could be seen from below projected against the sky, they appeared even slightly concave in cross profile.

In continuing my journey down Lynn canal, I visited the Davidson glacier, and also saw the Eagle, Lemon creek, and Juneau glaciers, and several others scarcely less important but still unnamed. Many of these descend practically to sea-level, although their extremities are commonly separated from the water by morainal deposits half a mile or so in width. Their surfaces, like the surfaces of the glaciers examined near the head of the same inlet, are remarkably free from débris, and terminate in a variety of ways.

Fan-shaped Terminals.—In every instance where well-defined ice streams were observed to descend from lateral cañons into broad valleys, and consequently are unconfined by the neighboring mountain slopes, they expand in all directions so as to form fan-shaped or semicircular termini, similar to the delta-like terminus of the Rhone glacier. This expansion of glacial ice, when not encumbered by moraines and free to move in all directions, takes place apparently without reference to the direction in which the glaciers flow. The Davidson glacier furnishes a typical example of the phenomenon here referred to. In the lower part of the gorge through which it descends, it flows a little east of north. Another example, equally typical, occurs in a valley tributary to Taiya valley, immediately south of Mt. Emmons. This glacier flows about southwest down a lateral gorge and enters a broader valley nearly at right angles. Like the Davidson glacier, it ends in a nearly symmetrical fan-shaped terminus. A third example of the same character is furnished by the Norris glacier of Taku inlet, some fifteen miles east of Juneau. This glacier, I am informed, flows about southeast and ends in a fan-shaped ice-foot, as is well shown in an illustration recently published by G. F. Wright.* The absence of débris on the surface of this glacier is indicated in that illustration.

These and other examples that might be cited seem sufficient proof that Alpine glaciers, when unencumbered by moraines, expand in all directions without reference to their direction of movement, and form characteristic fan-shaped termini of the Rhone glacier type when they advance on to a plain.

Recession of Glaciers about Lynn Canal.—The presence of bare fields of débris about the extremities of many of the glaciers in the neighborhood of Lynn canal, indicate that the ice streams of that region are receding. This is well illustrated by the bare and rugged piles of fine débris which encircle the expanded foot of the Davidson glacier. Several cirques and steep glaciated troughs in the same region, and also at various points farther south along the " Inland Passage," which are bare of vegetation and have recently been abandoned by ice, bear testimony in the same direction. The conclusion that the glaciers of southern Alaska are retreating is in harmony with G. F. Wright's observations on the recession of Muir glacier.† This recession is apparently a continuation of the general glacial retreat initiated when the Cordilleran glacier reached its maximum expansion.

Distribution of Glaciers in Alaska and accompanying Climatic Conditions.—Certain facts concerning the distribution of living glaciers in Alaska and their dependence on existing climatic conditions are so obvious that I venture a few tentative remarks in this connection.

*The Ice Age in North America. New York, 1889; fig. 18, op. p. 29. A small illustration of the Davidson glacier is given on page 29 of the same book.

† Loc. cit., p. 53.

The absence of perennial snow on the mountains of the Yukon region has already been referred to. A similar absence of snow has been reported by McConnell along the lower McKenzie. The reader will recall also that the glaciers on the north side of the Coast Range of Alaska are very much smaller than, and do not descend nearly so far as, the glaciers on the south side of the same range. Closely related to the distribution of the glaciers are certain climatic phenomena.

In the Yukon region the winters are long and extremely cold; a temperature of minus 80° Fahrenheit, I have been informed, not being uncommon. The mean annual temperature of this region as shown by Dall* is between ten and twenty degrees Fahrenheit. The snow-fall, however, is not great; perhaps two or three feet, on an average. The summers, though short, are pleasant, and hot enough to melt the winter's snows. The large number of hours of sunshine in summer greatly assists in raising the mean temperature at that season.

On the southern coast the winters, though long, are not severe, a fall of the thermometer to zero Fahrenheit, being seldom experienced at Juneau or Sitka. The snow-fall is heavy on the mountains, and rain is abundant on the immediate coast. The summers are cloudy and wet, with much fog; the number of clear days being few. The mean annual temperature on the coast as given by Dall* is in the neighborhood of forty degrees Fahrenheit. The rainfall during the only year in which continuous observations were made at Juneau was over 103 inches.†

These observations show that the abundant precipitation on the southern coast of Alaska, accompanied by a low mean annual temperature (due especially to a cool and cloudy summer), has resulted in the formation of vast ice-fields from which magnificent glaciers descend to the sea.

The excessively cold winters of the interior, followed by comparatively clear and warm summers, are not accompanied by an accumulation of perennial snow even on mountains three to four thousand feet high and situated under the Arctic circle.

The southern shore of Alaska rises from the ocean to a great height, and furnishes a cold surface against which the warm, moist southern winds impinge and are forced upwards. These favorable conditions for the formation of glaciers are still farther augmented by the presence of warm currents in the Pacific. A vast evaporating surface and a cold condensing surface are here close together.

The intimate dependence of the Alaskan glaciers on existing topographic and climatic conditions suggests certain interesting hypotheses in reference to the occurrence of continental glaciers in other regions and perhaps in various geological epochs.

* Pacific Coast Pilot, second series, U. S. Coast and Geodetic Survey, Washington, 1879, pl. 26.
† MSS. of observations made by Karl Koehler from Nov. 1, 1883, to Nov. 1, 1884.

As previously stated, the freshness of glaciated surfaces in the region occupied by the Cordilleran glacier is such as to indicate that the great ice-field of the northwest coast of this continent was of more recent date than the Labrador ice-sheet. A study of the junction of those two great areas of glaciation would be instructive, and might show whether the ice records of one area overlap those of the other.

If it can be shown that the various areas of former glaciatian in the northern hemisphere were not occupied by ice at the same time, but had independent histories, it is evident that the much-discussed question of the cause of the glacial epoch would be greatly simplified. This is a difficult proposition to demonstrate, but it seems to be the direction in which glacial studies are leading.

In Alaska there is a glacial area of the continental type in which the maximum of ice occupation has passed, and the ice-sheet is fast retreating. In Greenland there is another vast area occupied by a glacier of the same type which is apparently still increasing. In the northeastern states and the adjacent portion of Canada, in northwestern Europe, and probably in central Asia, continental glaciers existed at a recent date, but have disappeared. A study of what may be considered local conditions in these various areas should show whether variations in ocean currents and land elevation are capable of producing glaciers of the continental type. At present the observations are insufficient for such comparative study.

The hypothesis that continental glaciers, like those of the Alpine type, are individually dependent on local climatic and geographic conditions, if sustained, can be used in explaining the presence of glacial records in ancient formations without invoking great revolutions in the earth or changes in its cosmic relations. If the extinct continental glaciers of the northern hemisphere were not contemporaneous, it is apparent that we are now living in a "glacial epoch" as truly as was Pleistocene man. The Ice Age still lingers in Alaska, and has not yet reached its maximum in Greenland.

WASHINGTON, D. C., *January* 12, 1890.

DISCUSSION.

Professor N. S. SHALER: I should like to ask Mr. Russell if the facts observed by him in Alaska are consistent with the supposition that the non-glaciated portion of the country was beneath the level of the sea during the glacial epoch?

Mr. RUSSELL: My observations do not favor such an hypothesis. Just where the coast line was in Alaska during the glacial epoch remains to be determined.

President T. C. CHAMBERLIN: I should like to inquire as to the relative age of the glaciation. Is it young or old?

Mr. RUSSELL: The records are extremely fresh. On limestone hills near Lake Lebarge, which could not have been protected by superficial deposits since the glaciers retreated, fine striations still remain. The glaciation is perhaps fresher in appearance than it is in the Sierra Nevada mountains.

President CHAMBERLIN: The observations of Mr. Russell have a very important bearing on our general conceptions of the Pleistocene period, especially as to its great agency. It seems that we can now safely say that this agency was excluded from the northwestern corner of our continent. It also appears from evidence from Siberia that glaciers may be excluded from that still more extended region; for, while there are evidences of glaciation in the mountains on the southern border of Siberia, it does not appear that the extent there was more than would be accounted for by a slight increase in the precipitation of that region. The Pleistocene glaciation gathered about the north Atlantic, while the region of the north Pacific was free from it.

Professor SHALER: I am very glad to testify along with the last speaker as to the importance of these observations. I think they enable us to bring the glacial question—the question of the last glacial period—down to a very simple issue. I think I could safely undertake to re-create a glacial period in this part of the continent, if we could only manage the rainfall, leaving the temperature as it is. We have, for instance, at Mount Washington the conditions which just approach glaciation. I am inclined to think if the average rainfall there were twelve inches greater than at present, that amount coming in the form of snow, we would be likely to have a small glacial cap on the top of the mountain. Such an ice-cap would breed its own climate. A considerable increase of the snow-fall in New England would, I think, most likely set up glaciation over a large part of its surface.

President CHAMBERLIN: Coincident with this limitation in distribution, we are approaching a demonstration—if we have not already reached it—that in the first glacial epoch pre-eminently, and in the second glacial epoch measurably, there was a low condition of the surface; and the old

doctrine of a northern elevation as a cause of glaciation seems to be excluded by present disclosures. It seems to me that by the above line of observation we have almost excluded extra-terrestrial causes, and by the demonstration of the lower altitude of the surface we have excluded those causes that were relied upon by Lyell and others in the earlier days. It seems to me, further, that it is impossible to account for the glacial period by any supposable change in precipitation. We have, in the north Pacific region, at the present time, the most extraordinary precipitation, and yet we find that these Alaskan mountains are not the centers from which extensive glaciation radiates. I therefore find very grave difficulties in connecting the former glaciation with any climatological change that can be supposed to have taken place with the earth's axis of rotation where it now is.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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NOTE ON THE PRE-PALEOZOIC SURFACE OF THE ARCHEAN TERRANES OF CANADA.

BY ANDREW C. LAWSON, PH. D.

(*Read before the Society December* 27, 1889.)

CONTENTS.

INTRODUCTORY REMARKS.

Since the establishment of the glacial theory the cause of the hummocky and *roches moutonnées* character of the rocky surface of the Archean terranes of North America has generally been ascribed to the action of the ice of the glacial epoch. Two opinions have been prevalent, having this belief as their basis. The first and older view was, in accordance with the theories promulgated by the Scotch geologists, that the hummocks and their complementary hollows were produced by the direct plowing or gouging action of glacier ice loaded with rock débris. The second and more modern view is, that just as south of the terminal moraine we find the crystalline rocks extensively decomposed *in situ*, so prior to the advent of the glacial epoch the Archean terranes of the north were similarly decomposed, and the present hummocky

surface represents the locus to which rock decay had extended in depth. In this view the ice simply removed the rotten rock, scouring and polishing the fresh surface upon which it rested, and the hummocky character is due rather to the principles which govern the decay of rocks than to ice action, which is only held responsible for laying the surface bare. All students of glacial geology will concede that in both of these opinions there is a certain amount of truth, though much more in the second than in the first.

Some observations, however, which the writer has been enabled to make at odd times during the past few years, indicate that these hypotheses do not afford us the correct explanation of the hummocky aspect of the Archean surface, but that the latter, in its essential and prominent features, long antedates the glacial epoch, and was as characteristic of the surface upon which the earliest Paleozoic sediments were deposited as of that upon which the great Canadian glacier rested in glacial times. These observations have been made along the northern limit of the undisturbed Animikie and Nipigon strata, where they rest directly upon the Archean surface, on the north shore of Lake Superior, between Gunflint lake on the international boundary and the meridian of the Slate islands. The conclusions which they forced upon the writer have been confirmed by an inquiry which he has made into the conditions which prevail along the line of contact of the undisturbed Paleozoic rocks upon the Archean in more eastern portions of Canada.

In a paper of the present compass it will scarcely be possible to do more than indicate the localities where the evidence may be found, and to sketch the latter at each place in scant outlines.

The Phenomena of Central Canada.

Contacts between the Animikie and the Archean.—On the north side of Gunflint lake the superposition of the northern edge of the Animikie upon the Archean is well seen. To the north of the edge of the Animikie formations the Archean rises in low hummocky hills, the ridges of which, when these are present, coincide with the strike of the rocks. This hummocky surface may be walked over close up to the Animikie, and it may be seen to form an undulating surface upon which the latter rests. At the west end of the lake, on the north side of Black-fly bay, on mining locations R. 315 and R. 317, is an outlier of the basal beds of the Animikie resting on a ridge of Laurentian gneiss, with hollows on either side of it, and the Animikie at the bottom of that on the south, the whole showing very clearly that the present shape of the surface of the Laurentian was practically that upon which the Animikie was laid down. The direct repose of the flat Animikie upon the upturned edges of the Keewatin schists is also observable a mile and three-quarters from the east end of the lake, and here the surface

is of the same uneven character as that of the uncovered, glaciated country to the north. Similar contacts may be seen inland a short distance, near the head of the lake; and on Gunflint river the Laurentian gneiss, in low *roches moutonnées*, appears partially encircled by the Animikie rocks.

On the north side of North lake there flows in a creek at the bottom of a deep gorge, which cuts down through 200 feet of flat Animikie strata to the basement of Laurentian gneiss upon which they rest; and the basement is distinctly *roches moutonnées*. Similar conditions are observable two miles up the creek which flows into the east end of North lake, and on Sand lake, where escarpments of Animikie strata overlook and appear to overlie a hummocky surface of Laurentian gneiss. The same is true of the escarpments in the vicinity of Little Gull lake.

To the north and northeast of Little Gull lake is a group of five small steep-sided, flat-topped hills, known as the Outpost hills, which are outliers of the Animikie, capped as usual with a sheet of columnar trap. The distance which separates them from the main area of these rocks varies from one to four miles. This space is occupied by a very hummocky and *roches moutonnées* stretch of Laurentian gneiss which maintains the general level of a line extending from the base of the Animikie on the face of the escarpment to the base of the same series, where it rests on the Laurentian at the foot of the Outpost hills. The writer has been over the ground between the escarpment and the hills; and Mr. E. D. Ingall, of the Geological Survey of Canada, who has examined the hills carefully, informs the writer that the actual base of the Animikie may be distinctly observed resting upon the uneven, hummocky Laurentian surface, the sections being perfectly exposed.

Less than half a mile above Kakabeka falls small outlying patches of the basal beds of the Animikie may be seen lying in the hollows of the mammillated surface of the Laurentian, and the latter, as it rises from beneath the Animikie, above the falls, is exceedingly hummocky.

Along the Dawson road, a few miles back of Port Arthur, low, rounded domes of Laurentian gneiss appear in the midst of the Animikie, projecting above the level of the local upper beds.

On Current river the Laurentian rises in hummocky hills from beneath the Animikie slates and traps, although the actual contact has not been observed. Between this and McLean's siding, seven miles east of Port Arthur on the Canadian Pacific railway, the Archean rises in the same hummocky hills from beneath the Animikie, the line of contact being concealed by a narrow strip of swamp. At the siding the contact is only concealed by the width of the road-bed, and the surface of the Laurentian gneiss is seen to plunge down under the flat Animikie rocks with the slope of a steep dome, appearing again in a less prominent but still hummocky outcrop close to the con-

beds of the Nipigon resting *in situ* in the hollows between the Laurentian hummocks, both at the bottoms of the hollows and on the steep slopes. These patches are usually not more than a few chains in diameter; and their relation to the Laurentian affords incontestable proof that the surface of the latter has undergone no material change since they were deposited upon it. At Rossport the Animikie rocks come in again between the Archean and the Nipigon, and here also may be seen, near the railway station, in a hollow between the Laurentian hillocks, an outlying patch of the basal beds of these rocks.

Along the shore of the lake between Rossport and Black river, north of the Slate islands, there are occasional patches of the Nipigon amygdaloidal traps which have escaped removal by erosive agencies, and these all repose upon a hummocky Archean surface. In none of these instances is there any evidence of a perceptible reduction of the mean level of the glaciated surface of the Archean below that upon which the Nipigon or Animikie rocks rest. A noteworthy fact also is, that with one exception none of the Archean rocks, where they pass immediately beneath the Animikie or Nipigon, show the slightest evidence of decay. On the contrary, they are remarkably fresh and free from even the incipient decomposition of weathering. The exception is the case of the schists in the rock cut east of Pearl river mentioned above. All the Laurentian gneisses and granites are perfectly fresh in their macroscopic aspects. Another interesting point, which will be alluded to again, is the transgression northward of the newer Nipigon rocks beyond the edge of the older Animikie.

The Phenomena in Eastern Canada.

On instituting a comparative inquiry into the conditions which obtain along the escarped line of the abutment of the undisturbed Paleozoic upon the Archean in eastern Canada, it is found that the evidence here confirms the conclusions arrived at on Lake Superior as to the general character of the pre-Paleozoic Archean surface.

Contacts between the Paleozoic and the Archean.—Laflamme in his "report of geological observations in the Saguenay region"* seems to have arrived at much the same conclusion as the writer. After describing a new area of the Trenton rocks in the vicinity of the Saguenay "which rest directly on the gneiss," and stating that "their thickness is so slight, at least on the border of the formation, that the undulations of the gneiss are brought to light through their edge," he gives an account of various outliers and says by way of summary: "I have pointed out in the course of these remarks the fact that limestones (Trenton) are often found in nests or outliers amongst the

*Geol. Survey of Canada, Report Progress for 1882-3-4, Part D.

granites. Therefore, these depressions and hills of Laurentian must necessarily have existed at the bottom of the Paleozoic ocean when the limestone beds were being deposited."*

Mr. A. P. Low, of the Geological Survey of Canada, who has been more recently engaged in tracing out the northern limits of the Paleozoic on the north side of the St. Lawrence, west of Quebec city, informs the writer that at several places he has noted the superposition of the Trenton or Lorraine beds directly upon the hummocky Laurentian surface, and that there has been no reduction of the surface where it projects from beneath the escarpments, below that where the flat strata rest upon it. He notes the following localities as affording particularly good sections:—Between Lorette village and St. Ambrose railway station, Q. L. St. J. railway; west of Belair station, C. P. railway; Pont Rouge station, C. P. railway (section on Jacques Cartier river); Deschambault, near railway station. Mr. Low also informs the writer that the undisturbed limestones of Lake Mistassini, in southern Labrador, may be observed to rest upon hummocky Laurentian surfaces; and that on the East-main coast of Hudson's bay similar flat lying strata may be seen in the transverse section afforded by Richmond gulf, resting on a very hummocky surface.

In eastern Ontario, the best evidence we have bearing on this question is contained on Mr. E. Coste's "Geological and Topographical Map of the Madoc and Marmora Mining District," recently published by the Geological Survey of Canada. No report accompanies the map as yet, but the writer has had the benefit of frequent conversations with Messrs. Coste, Ami, and White, who were employed in the field-work necessary for its construction. From the map and from the information thus supplied, it is clear that in the area mapped we have a remarkably striking illustration of the superposition of flat, undisturbed Paleozoic strata (Birdseye and Black River) upon a very hummocky and mammuillated Archean surface. The northern border of the Paleozoic is here very irregular in outline, and beyond the limit of the main area there are very numerous outliers scattered over the country. Both along the edge of the escarpment and at the periphery of many of the outliers, the flat strata may be seen resting directly on the rounded hummocks; and these, out beyond the escarpment, often rise high above the lower horizontal strata. Many of the outliers, also, are mere patches resting *in situ* upon the steep slopes of these hummocks. Many are but a few chains in diameter, and others only a few yards. Further, there may be repeatedly seen projecting through the upper surface of the Birdseye and Black River formations rounded knobs of the Archean, in the shape of inliers well within the Paleozoic area. These are clearly the crests of partially

* Loc. cit., p. 15.

uncovered hummocks; and the phenomenon is so common as to leave no doubt as to the character of the underlying surface.

Review of the Evidence.

Thus, wherever careful observations have been made as to the nature of the superposition of the undisturbed Paleozoic rocks upon the Archean, whether in the Lake Superior country, eastern Ontario, Quebec, or Labrador, the evidence points to the same conclusion, *i. e.*, that the early Paleozoic rocks were laid down upon a surface which did not differ essentially from that presented by the exposed Archean surface of the present day upon which the great Canadian glacier rested; and that there is no good evidence of that surface having undergone any material reduction in level, in consequence of the conditions of the glacial epoch, either by any plowing power sometimes ascribed to glacier ice, or by the removal of the products of extensive rock decay.

General Considerations.

In the foregoing pages the evidence, although briefly sketched, has been specific, and attention has been confined to the immediate vicinity of the edge of the Paleozoic formations. Let us turn now to a somewhat broader aspect of the question.

Former Extension of the Paleozoic.—There is excellent presumptive evidence that the greater part, if not the whole, of the Canadian Archean terranes were at one time covered by Paleozoic strata, and the assumption so generally made that they have always formed an upland region, serving as a source of supply for the sediments which built up the Paleozoic formations, appears to be scarcely warranted by the facts.

The reconnaissance work of the Geological Survey of Canada, while it has only effected an examination of a number of linear sections across the arms of the V-shaped Archean nucleus, along the various canoe routes which traverse it from the waters of the St. Lawrence and Lake Winnipeg systems to the waters of Hudson's bay, has yet established the fact that there are basins and outliers of Paleozoic rocks scattered over its surface which appear to be but the remnants of once far wider spread formations. In the region of the Saguenay, Laflamme * has described various outliers of Trenton other than the well known one at Lake St. John, and the distribution of these shows clearly that this formation must have extended for at least 150 miles north of the St. Lawrence, over what is now for the most part bare Archean surface, and the probability is that it extended much farther.

* Op. cit., pp. 10-15.

To the north the explorations of McOuat and Low have established the existence of another large and important outlier of undisturbed Paleozoic rocks over 100 miles in extent, about 150 miles beyond Lake St. John, at Lake Mistassini. These rocks are chiefly limestone in which as yet no fossils have been found, and which are referred provisionally to the Cambrian from certain resemblances to the flat strata of the east coast of Hudson's bay which are supposed to be of that age. These latter rocks occur along the East-main coast, resting in undisturbed attitudes upon the Archean. Inland from this coast, also, Mr. Low found in the drift which comes from the east, or the interior of Labrador, a limestone boulder containing Silurian fossils, which indicates the presence of an outlying area of such rocks in that region.*

On the upper Ottawa, in the vicinity of Pembroke, we find extensive Cambro-Silurian outliers as much as 50 miles from the edge of the present main Paleozoic basin. Other outliers are also found on the islands of Lake Nipissing, and on Lake Temiscaming nearly 100 miles north of Lake Nipissing. There is thus good reason for supposing that the Paleozoic seas extended far over the whole of the upper Ottawa country.

The great Siluro-Devonian basin of the west side of James's bay extends southward to within 100 miles of the north shore of Lake Superior, and farther west the rocks of the Nipigon basin extend northward for 100 miles. The former extends south and the latter north of the 50th parallel of latitude, and the east and west distance between the two basins along the parallel is only about 100 miles. It is entirely probable that both of these basins only represent what is left by erosion of a much more extensive distribution of the respective formations constituting them ; and that they do not in reality correspond in area to the original basins of deposition, but are rather basins of shelter from erosion, such as all the Paleozoic outliers appear to be.

On the southwest side of Hudson's bay there is another extensive area of Silurian rocks, traversed by the lower stretches of the Churchill, the Nelson, the Hayes, and the Severn rivers. These rocks resemble those of the same age in the basin of the Red river and Lake Winnipeg, both as regards their fossil remains and their lithological characters. The Hudson's bay area of these rocks is separated from that on Lake Winnipeg by about 200 miles of Archean country, with no prominent elevations between, and it is therefore quite probable that they were once connected, and that the formations of which they are constituted extended continuously across this northwestern arm of the V-shaped Archean "nucleus." An outlying area of sandstones of unknown age also rests upon the Archean at the east end of Athabasca lake.

Thus, considering the very limited extent to which this Archean "nucleus"

* Geol. Survey of Canada, Annual Report, Vol. III, 1887, Part J, p. 59.

has been explored, the indications that it was once very extensively if not wholly covered by formations of Paleozoic age are both numerous and important. The lines of examination have been chiefly confined to the ordinary routes of travel followed by the fur traders, and these are not numerous. When the country comes to be more closely explored there is every reason to suppose that many other outliers, such as those of lakes St. John, Mistassini, Nipissing, and Temiscaming and the Ottawa river, will be found scattered over its surface, and that the evidence of the once wide-spread distribution of the Paleozoic formations will accumulate.

Transgressions and Oscillations in Level.—But here a word of caution and modification is necessary. While the evidence indicates that a covering of Paleozoic (Cambrian to Devonian) once spread over the Archean surface, it does not indicate that the rocks of the lower horizons were thus widely spread. On the contrary, it is to be noted that there are distinct evidences of the transgression of the formations of higher horizons over the limiting edges of the lower. Thus, on Lake Superior, the Nipigon rocks may be distinctly observed to overlap the northern edge of the Animikie formation and extend northward far beyond it. In the St. Lawrence and lower Ottawa region, rocks of Potsdam and Calciferous age are abundant. Further north these are absent, and in the upper Ottawa outliers the Chazy rests directly upon the gneiss. In the vicinity of Madoc this also is lacking, and the Birdseye and Black River beds rest directly upon the gneiss. This appears to be true also of the outliers on Lake Nipissing. Thus, in ascending the Ottawa, the Chazy overlaps or transgresses both Potsdam and Calciferous, while at Madoc and Nipissing all of these are transgressed by the Birdseye and Black River. This, in turn, and all older formations, were transgressed by the Niagara, as is indicated by beds of that age resting directly on the Archean on Lake Temiscamany.

In the Province of Quebec the same condition of affairs is found. In the vicinity of the St. Lawrence, the Chazy and Calciferous rocks abound. To the north of this, in the Saguenay country, Laflamme remarks as a noteworthy fact, that in all the points of contact which he has been able to observe between the Laurentian and the Trenton, the latter rests directly upon the former, no traces of Potsdam, Calciferous, or Chazy being seen. Moreover, whilst the Utica formation is present only in a few instances, still débris from it are found on the shores of the lake (St. John), and very often inland to such an extent that we are forced to conclude that the whole area of the Trenton was formerly covered with this formation.

Thus, while the evidence indicates that the Archean "nucleus" was once covered very extensively by Paleozoic formations of one horizon or another, it appears probable that it was not extensively submerged till the time of the Trenton, and that it was much more extensively submerged during the

deposition of the Niagara than in earlier epochs. It would follow from these considerations, that as Paleozoic time advanced from Cambrian to late Silurian or Devonian there was a gradual and progressive subsidence of this portion of the continent. As we have no evidence of the deposition of post-Devonian formations anywhere over the Archean "nucleus" till we come down to post-Tertiary, it may be tentatively inferred that after the Devonian it was again elevated, and this elevation probably only reached its maximum during the glacial epoch, affording the conditions of altitude contended for by many writers to explain the great precipitation of snow. In post-glacial times we know from the distribution of such formations as the *Leda* clay and *Saxicava* sand that the northern part of the continent was again partially submerged for several hundred feet, from which depression it has since recovered; we thus have evidence of a slow ve.tical pulsation of the surface of this part of the continent, of which there have been at least four great beats since early Cambrian times.

But this is a digression, and the argument which has led to these remarks was inaugurated to show simply that the surface of the Archean "nucleus" was once very extensively if not wholly covered by Paleozoic sediments. This covering probably accounts in a large measure for the remarkable preservation of the Archean surface in the condition in which pre-Paleozoic denudation left it. There are other considerations which help us to understand this preservation, such as the levelness of the plateau and its comparitively low altitude, combined with the very resistant character of most of its rocks, which appear to be little susceptible to that erosive or corrasive action of streams which is so effective in removing the more yielding strata of post-Archean age. These considerations will not, however, be entered upon here.

The Erosion of the Archean.—One is constantly impressed by the perfectly appalling amount of denudation to which the Archean has been subjected in order to truncate its formations down to the surface which it presents to-day. And when we reflect, as a result of the conclusions here arrived at, that this denudation was practically completed before the beginning of earliest Paleozoic times, and has not been, as commonly supposed, the result of later agencies, there looms up a conception of the pre-Paleozoic interval necessary for such denudation which staggers even the most stalwart geological imagination. To say that it must have been comparable with all the time which has succeeded from the earliest Cambrian to the present seems but a feeble way of expressing it.

Source of Paleozoic Sediments.—The conception of a covering of Paleozoic strata over the surface of the Archean "nucleus," which probably endured into comparatively recent geological times, enables us to a large extent to understand the preservation of the pre-Paleozoic surface, but it also raises the

important question of the source of the sediments composing those strata. If such a wide-spread formation as the rocks of Niagara age was deposited over the surface of the Archean "nucleus," as well as over the regions which encircle it, it is clear that the Archean "nucleus" could not have been the source of supply of those sediments. Some other portion of the continent, or some other region now submerged, must have constituted the dry land of that time. Where that region lies is a question yet to be answered.

DISCUSSION.

Professor J. W. Spencer: The facts set forth in this very interesting paper by Dr. Lawson have their counterparts in the geological structure of the South. The hummocky and rounded rock surfaces have always had an interest for me, on account of their common occurrence in regions which have been glaciated, and hence regarded by many as evidence of glacial erosion. But in the paper of Dr. Lawson we learn that such surfaces existed before the formation of the early Paleozoic terranes. Some of you may be familiar with Stone Mountain, about fifteen miles from Atlanta, Georgia. This is a rounded granite hummock of over a mile, in longer diameter, rising 700 feet above the plain. The rock is remarkably free from joints, and is rarely traversed by even an insignificant vein. Thus its structure has been favorable to the preservation of the rounded form, whose outline is as perfect as any of the domes of glaciated Norway or Canada; or of southeastern Missouri, which lies outside of former glacial action. Stone Mountain rises from beneath very much disturbed strata of gneiss, whose beds dip to the southeast, and there is no gradation of any importance between the granite and the gneiss. The gneiss is decayed to a depth, in some places, of at least sixty feet; but the granite is compact, without being weakened by even incipient decay. The surface materials, as fast as decomposed, are washed off by the rains. Thus the contrast between the two formations of rocks is preserved. This Stone Mountain is only one of many in Georgia and Alabama. Here, then, we have, in the South, pre-Paleozoic surfaces as old as or older than those described by Dr. Lawson in the Lake Superior region, and brought to light by simple atmospheric action. Along the Potomac river we find hummocks being formed by the progress of atmospheric invasion along lines of joints, but these are now in process of formation, and do not represent so ancient surfaces as those of the granite hummocks of the South.

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THE INTERNAL RELATIONS AND TAXONOMY OF THE ARCHEAN OF CENTRAL CANADA.

BY ANDREW C. LAWSON, PH. D.

(*Read before the Society December* 28, 1889.)

CONTENTS.

Primary Separation of the Archean into two Divisions.

Throughout North America, geologists have long recognized in the great fundamental complex of rocks, known generally to-day as the Archean, a natural division into two well-characterized portions, related to each other in space as upper and lower. The lower division is commonly known as the Laurentian, and consists for the most part of an assemblage of rocks of the character of granites, syenites, diorites, and gabbros in mineralogical composition, but more or less foliated or gneissic. Involved with these in a way not hitherto understood there are also, in some regions, portions of

various gneiss, schist, limestone, quartzite, and conglomerate formations, which, not being easily separable from the foliated granite rocks, have been sometimes classed with the latter as Laurentian.

The Upper Division.

Nomenclature.—The upper division is of very varied lithological character, and various names have been applied to it, or to portions of it, in different regions. Until recently it has been customary to apply the term Huronian to a part of this upper division on account of its supposed equivalence to the series of rocks so named by Logan and Hunt in 1855.* But if the original conceptions of these eminent geologists and the more recent contentions of Irving, corroborated by Professors N. H. Winchell and A. Winchell, are correct—viz., that the Huronian and Animikie are geologically equivalent,—then we cannot in reason perpetuate the incongruity of applying the same name to two groups of rocks which lie one on either side of probably the greatest hiatus in American geological history. The term Huronian must be retained for the group of rocks on Lake Huron first so named and its equivalents; and, in view of the evidence which has been adduced of the unconformable superposition of that group upon the Archean and its probable equivalence with the Animikie, which rests upon the Archean in glaring unconformity, it seems inappropriate at present to apply the term Huronian to any portion of the Archean. We are thus, at the outset of any inquiry into the Archean, hampered by the lack of an acceptable designation for the great system of rocks which constitutes its upper division. Even if the Huronian group be demonstrated to lie upon the remote side of the great post-Archean hiatus, it would then be only one of several groups that go to form the system which constitutes the upper division of the Archean complex, and the system itself would still be nameless. At least one other great group of rocks—the Coutchiching (possibly the equivalent of the Montalban of Hitchcock)—has been brought to light, which is not second in taxonomic importance to the various belts of rocks similar to the Keewatin, which have been correlated with the Huronian. So, granting that the Huronian shall one day hold an unchallenged position in Archean taxonomy, it will not have a higher rank than that of a group.†

* A Sketch of the Geology of Canada, serving to explain the Geological Map and the Collection of Economic Minerals sent to the Universal Exhibition at Paris, 1855, by W. E. Logan and T. Sterry Hunt; in Canada at the Universal Exhibition of 1855, p. 415 *et seq.* In this sketch, in which the term Huronian is first defined, the rocks now known as the Animikie and Nipigon series are taken together as the equivalent of rocks on Lake Huron, and the whole is called the "Huronian or Cambrian system," which is stated to rest unconformably upon the Laurentian.

† In this paper the terms "system" and "group" have the significance assigned to them by the United States Geological Survey, in the scheme published in the Second Annual Report, 1880-'81, p. xlviii. The writer recognizes, however, two great "systems" in the Archean complex. The terms may later be transposed or otherwise changed to accord with any general decision of the International Geological Congress as to usage.

Having these considerations in mind, it seems desirable, in the cause of the concise expression of our knowledge and of the furtherance of clear and simple conceptions of Archean geology, that the taxonomic value of this upper division of the Archean should be recognized by the adoption of an appropriate designation of systemic import. There is probably no other equal area of the earth's surface where the formations of this system are better or more extensively exposed than in the Canadian province of Ontario. The writer therefore begs to suggest to his fellow-workers in American Archean geology that this system be known as the *Ontarian System.*

Petrographical Description.—The formations of different groups of the Ontarian system present for the most part a sharp contrast in lithological character and mode of occurrence to those of the Laurentian system. The latter, as has been indicated, consists essentially of an assemblage of more or less foliated or quite massive varieties of rocks which are to-day recognized by petrographers as plutonic igneous rocks—*e. g.*, granites, syenites, diorites, gabbros, etc. The former is composed of rocks which are with varying degrees of certainty recognized as normal sedimentary and volcanic formations disguised by metamorphism of different kinds. Among the more easily recognizable formations may be mentioned conglomerates, grits, quartzites, graywackes, clay slates and limestones; various pyroclastic rocks, such as ashes, tuffs and agglomerates; and massive volcanic rocks, both acid and basic, notably quartz-porphyries and diabases; all of which rocks, far from being peculiar to the Archean, are normal constituents of Paleozoic and later geological systems. In all of these, schistosity may be a feature of the rock.

With these normal or only slightly altered rocks occur also more highly altered facies of the same formations, whose derivation is known, and others still more differentiated from unaltered types, whose historical derivation from normal rocks cannot be traced with certainty, but only inferred by analogy as highly probable. Of those rocks whose original character is more or less obscured, the most prominent are certain phyllites, mica schists and feldspathic mica schists or gneisses, so called; hornblende schists and amphibolites, serpentines, soft, dark, glossy, green schists, and various light-colored acid porphyroid schists, nacreous sericitic schists and felsitic schists with quartz grains. These are all rocks upon which there has, in recent years, been concentrated a great amount of research both in the field and in the laboratory, and many facts have been established concerning them in various parts of the world which enable us to formulate definite and well-grounded conceptions as to their origin and development, where formerly only more or less indefinite speculation was possible.

The rocks known as phyllites or phyllitic schists are very common in fossiliferous series in disturbed regions, and their clastic origin is rarely ques-

tioned. In the Archean, rocks of this and more pronounced micaceous character to true mica schists are traceable into clay slates and siliceous clastic rocks with unobscured original characters. Other mica schists are directly traceable into conglomerates and agglomerates, and appear to be but excessively squeezed facies of these rocks where the conglomeratic or agglomeratic characters have been obliterated and much mica developed. And in some mica schists, where no direct transition can be established, traces of conglomeratic structure can occasionally be detected. The most distinctly crystalline of these mica schists are entirely comparable with the mica schists of the Bergen peninsula in Norway, where Reusch a few years ago found beautiful Silurian fossils,* some of which the writer has himself more recently collected under the guidance of that distinguished geologist.

Many mica schists of the Ontarian system are, further, entirely similar to the "hornfels" or crystalline schists of the contact zones of various post-Archean granitic irruptions, which are undoubtedly the altered facies of normal sediments. Some of the feldspathic mica schists, of a fine-grained, thinly laminated aspect, commonly called gneisses, are in parts of the Ontarian system traceable into quartz-porphyries of the same normal character as those which constitute the volcanic portions of many Paleozoic series. The researches of Lehmann † have established such transformations as facts, the explanation of which, as demonstrated by that eminent investigator and now generally accepted, is found in the deformation of the rock by pressure and in the chemical activity induced thereby. For the most part, however, the feldspathic mica schists, such as are abundant in the Coutchiching group, are, like the non-feldspathic mica schists associated with them, very probably of metamorphic derivation from normal sediments.

In portions of these formations the writer has recently detected vestiges of conglomeratic structure. In places they pass into rocks that are little more than slightly micaceous quartzites, and their distinct bedding and regular stratigraphy are those of sedimentary rocks as contrasted with the lenticular arrangements which obtain in volcanic accumulations. Their contact phenomena against the granites and granite-gneisses of the Laurentian are identical, so far as studied, with intrusive granites, particularly in the development of andalusite crystals. They correspond closely in lithological character and in the nature of their relations to the Laurentian with the descriptions given us by Barrois ‡ of the feldspathic mica schists of Cambrian age, which in Brittany are pierced and altered by great irruptions of granulite (the true granite, or granite with two micas, of the Germans), which rock forms very extensive portions of the Laurentian northwest of Lake Superior.

* Die Fossilien Führenden Kryst. Schiefer von Bergen. Leipsic, 1883.
† Entstehung der Altkrys. Schiefergest. Bonn, 1884.
‡ Comptes Rendus des Excursions de la Soc. Geol. de France dans le Finistére. Bull., 3me Série, t. XIV, 1886, p. 832, et seq.

As to the hornblende schists, the field evidence points to their derivation from basic volcanic rocks. In places this derivation can be traced step by step from the massive rock to the schist; but for the most part no such transition is observable, and at the base of the Keewatin, in contact with the Laurentian, there is commonly found a formation of hornblende schists of whose origin and development we can only judge by comparison with cases where the history of similar rocks has been thoroughly worked out and established beyond question. Teall,* in Scotland, and Reusch,† in Norway, have shown that some typical hornblende schists and more chloritic hornblende schists may be produced by the shearing of diabase dikes. The writer has collected specimens of the crushed and squeezed diabase dikes of Bömmelö described by Reusch, which are indistinguishable from many of the schists of the Keewatin on the Lake of the Woods and Rainy lake. Teall's description of the hornblende schists resulting from the shearing of dikes would also apply to many of the Keewatin schists which occur in bedded formations. The augite-porphyrites of the Silurian of the southeast coast of Norway, which have been described by Brögger,‡ are, at the contact with the intrusion of the augite-syenite of Laugesundfjord, where observed by the writer, altered in places into black glistening hornblende schists, which are very similar to the hornblende schists of the Keewatin at its contact with the Laurentian gneisses. Thus, both the conclusions arrived at in the field and supported by microscopic studies, and the analogies furnished by the investigations of geologists elsewhere, point to the derivation of the bulk of the hornblende schists from normal volcanic massive rocks, which were originally bedded with other stratified rocks, either as flows or as injected sills. Other hornblende schists are probably derived from an analogous alteration of tuffs of basic volcanic rocks.

The amphibolites are rocks very analogous to the hornblende schists in mineralogical composition, but massive or non-schistose in structure. They have probably undergone the same chemical development as the schists, with pressures so adjusted that no foliation was induced. They are comparatively local in their occurrence and do not generally make extensive formations.

The various serpentines, so far as they are known, are for the most part beyond doubt the alteration products of local bosses of highly magnesian, massive irruptive rocks. This conclusion is based not simply upon the investigation of the rocks of this particular field by the writer, but upon the numerous instances that might be cited from the petrographical writings

* Metamorphosis of Dolerite into Hornblende-Schist; Quart. Jour. Geol. Soc., Vol. XLI, May, 1885, p. 133.
† Bömmelöen og Karmöen med omgivelser geologish beskrevne, 1888, pp. 392–397.
‡ Spaltenverwerfungen in der Gegend Langesund; Nyt Magazin for Naturvidenskaberne, XXVIII Bind, 3die—4de Hefte, p. 352.

of recent years, establishing such an origin for the bulk of the serpentines at present known the world over.

There is a great variety of fissile, more or less glossy, rather soft, green schists, partly hornblendic and partly chloritic, the origin of which in some cases is closely fixed from the fact that they form the matrix of well characterized pebble and bowlder conglomerates. In this case they must have been composed of epiclastic or pyroclastic material. The writer inclines to the opinion that they are of proximately pyroclastic origin from the fact that precisely similar schists, free of pebbles, are frequently associated with massive or only slightly schistose diabases, as if the tuffs of these extravasations. There are many other bedded green schists some of which can be shown to be squeezed and otherwise altered facies of diabase, while the precise origin of others is yet quite obscure.

The porphyroid schists, the felsite schists with quartz grains, and many of the nacreous sericite schists, represent squeezed, schistose and otherwise altered forms of quartz-porphyries and petrographically allied rocks, and their tuffs, which, as before stated, enter not uncommonly into the composition of the volcanic portions of normal Paleozoic series. Some others of the sericitic schists may probably have been developed from sediments rich in orthoclase débris; but this, except where they pass over into rocks of the character of phyllites, is not so easily established as the direct derivation of many of them from the acid volcanic rocks.

Original Characters and Metamorphism.—From the foregoing statement, brief and incomplete as it is, of the broad lithological characters of the formations which constitute the Ontarian system, or upper division of the Archean, it must be apparent that, although there are rocks within it whose history is more or less obscured by the changes which they have undergone, the system is an assemblage of once normal rocks, all of which may be found even in their most altered phases in series of Paleozoic and later ages. This conclusion will not appear startlingly new to the very powerful school of American geologists, who have always claimed the metamorphic derivation of the whole of the Archean from normal rocks.

But, as will appear in the sequel, the metamorphic explanation of the whole of Archean phenomena is not tenable, and is only applicable, in the opinion of the writer, to its upper division, here designated the Ontarian system. Moreover, it is to be noted that the conclusion in question offers an important modification of the old view of the metamorphic development of such rocks as constitute this system, inasmuch as volcanic formations have scarcely been recognized in our leading American text-books as having a share in the composition of the older rock series. Much of the Archean was properly recognized as the alteration products of sediments, and the whole complex was therefore inferred or supposed to be of similar derivation from

sediments. It is only in very recent years that the possibility of the derivation of a portion of the schists of the Archean from volcanic rocks has been looked into and the important rôle played by volcanic agencies in building up the older rock series has been appreciated.* There are, however, not a few geologists who continue to advocate the extreme plutonic view that the whole of the Archean is of igneous origin and represents the first-formed crust of the earth. Hunt's crenitic hypothesis, also, is a challenge to the metamorphic theory.

In deference to these and other anti-metamorphic schools of thought, in which for the most part theory seems to crowd out fact, it becomes necessary, with the accumulation of evidence of recent years, to point out the great additional strength acquired by the theory of metamorphism as applied to the Archean, by the recognition of the volcanic origin of much of the material upon which metamorphic agencies have operated, and by the limitation of its application to the upper division of the Archean; the rocks of the lower division, or Laurentian, being susceptible of an entirely different explanation. The lack of discrimination between the essentially different characters of the upper and lower Archean and the lumping of the whole complex together as having necessarily the same origin and development has been the great mistake alike of the metamorphic and the extreme plutonic schools. Just as the metamorphic theory, properly limited, affords the explanation of the development of the rocks of the upper Archean from normal formations, so by a similar limitation of the plutonic theory and the introduction of some modifying considerations we will find in the latter a rational and consistent explanation of the origin of the rocks of the Laurentian.

Relations between the two Divisions.

The General Relations.—The full significance of the sharp separation of the Ontarian system, as a bedded assemblage of prevailingly schistose and otherwise altered normal rocks, from the Laurentian, as a non-bedded assemblage of more or less foliated plutonic igneous rocks, will appear from an inquiry into the relations in space and in time between these two great systems, which it is the object of this paper to institute.

That portion of the Ontarian system which for some years has been somewhat loosely referred to as Huronian, from its supposed equivalence with the rocks of Lake Huron, now held to be possibly post-Archean, presents in many parts of central Canada contacts or lines of junction with the Laurentian. The nature of this contact has been a subject of discussion. The question has ever been raised whether these rocks are conformable or un-

* The first suggestions of volcanic admixtures in the upper Archean rocks of central Canada were thrown out by G. M. Dawson in his description of the agglomerates of the Lake of the Woods in the Report on the Geology and Resources of the 49th Parallel, 1875, p. 52.

conformable upon the Laurentian; the assumption being always that both assemblages of rocks were composed of metamorphosed sediments. The answer was held to hinge upon the parallelism or absence of parallelism between the foliation of the Laurentian granites and syenites and the planes of bedding and schistosity of the rocks which are in contact with them. Bell, Dawson, Selwyn, and McKellar contended for a conformable sequence. Logan is silent on this question, but seems to have been in no doubt as to the unconformable superposition of the true Huronian of Lake Huron upon the Laurentian. Hunt has always contended for an unconformity, but as he also had in mind the true Huronian, which he once regarded as Cambrian, his contentions do not seem to apply to such rocks as are clearly Archean and intimately involved with the Laurentian gneisses. It is therefore fair to say that the drift of opinion in Canada, and probably also in the United States, is in the direction of conformable sequence throughout the Archean, without a break between the lower (Laurentian) and upper (Ontarian) systems. This view has recently been emphatically endorsed by Professor Alex. Winchell* as a result of his observations in northern Minnesota. Dawson has recently, as a result of his studies of analogous conditions on the Pacific coast, thrown over his earlier opinions as to the conformable sequence between these two divisions of the Archean on the Lake of the Woods, and is now in accord with the writer as to the nature of the relations which obtain there, and which will be set forth in the sequel.†

Irruptive Contact on Lake of the Woods.—Up to the date of the publication of the writer's report on the geology of the Lake of the Woods (1885), the possibility of any other relationship between the two great divisions of the Archean than those of conformity or unconformity do not seem to have been entertained. In that report the writer pointed out that the relationship was one of neither conformity nor unconformity, but of an entirely different order. Evidence was adduced in some detail to show that the conditions of the contact between the Laurentian and the Keewatin are essentially those which obtain between any Paleozoic or later intrusion of granite and the bedded rocks through which it breaks. The contact was shown to be a brecciated one, the granitoid gneiss ramifying through the schists in apophyses, both transverse and parallel to the strike of the schist, and holding in abundance fragments from the Keewatin formations, which had clearly been broken off from the latter while it was in a hard and brittle state and had found their way into the Laurentian often for considerable distances from the contact, as well as more notably in its proximity. The conditions observed indicate clearly that we had no question of conformity or unconformity to deal with, but with the contact of an irruptive igneous mass, of

*Geol. and Nat. Hist. Survey of Minnesota, 15th Annual Report, 1886, pp. 181, 190, et seq.; 16th Annual Report, 1887, pp. 335, 336, 350, 364, et seq.

† Annual Report Geol. Survey of Canada, Vol. II, N. S., 1886, p. 13B.

later formation than the schists of the Keewatin series, and breaking through them.

Irruptive Contact in Rainy Lake Region.—The studies here inaugurated about Lake of the Woods have since been continued into the Rainy lake region, and still farther eastward to Lake Superior. A portion of the results are contained in a recently published report of the Geological Survey of Canada.*

Throughout this region, it was found that the Keewatin is not the only group in the upper division of the Archean, but that another very voluminous group intervenes between it and the Laurentian, to which the name Coutchiching has been given.† The relations of the Laurentian to this group of schists was found to be the same as to the Keewatin, with even clearer and more abundant evidence of the irruptive and later origin of the Laurentian. With extended observations it was also noted that the bedded rocks of the Ontarian system, whether belonging to the Keewatin or Coutchiching, present a more highly altered or more crystalline and schistose facies in proximity to the contact with the Laurentian granite-gneiss than in the middle portions of the trough, where the rocks are frequently not greatly altered from the normal character of their analogues in Paleozoic formations.

In other words, there is evidence of contact metamorphism where the Laurentian rocks come against the shattered and ragged edge of the local base of the Ontarian system. All the conditions of contact, therefore, whereby we recognize any mass of granite to be irruptive through stratified rocks, are found to hold here between the rocks of the Laurentian and Ontarian systems. The detailed geological mapping of the country shows also that the Laurentian rocks, while continuous beneath the schist belts, come to the surface in areas which may be described as isolated bosses. Each of these is surrounded by a belt of the Ontarian rocks, usually in the form of a sharply folded trough sunk down into the Laurentian and separating the surface exposure of the boss from those of its neighbors. These belts of formations of the Ontarian system are, for the most part, compact and con-

* Annual Report, 1887, Part F.

† It is unfortunate that two new names have become current for this group of rocks. The term Coutchiching was proposed by the writer in a paper which left his hands in March, 1887, bearing that date, and which was published in the *American Journal of Science* in June of the same year. The geological position, lithological character, known geographical distribution, relations to Keewatin and Laurentian, and the importance and distinct individuality of this great group, were stated and discussed in that paper. In the Fifteenth Annual Report of the Geological Survey of Minnesota, bearing the date of May 1, 1887, but appearing much later, there is a multitude of valuable observations and details, but no systematic statement of the geology of the region; and the differentiation of the group in question, as geologically separable from the rest of the complex, does not appear to have been recognized at the time of the writing of the report, although the term "Vermilion series" occurs once, apparently as an afterthought, inserted on page 299 of Professor N. H. Winchell's report. On the maps accompanying the report, however, it is distinguished clearly by a color and named the "Vermilion series," although here including formations that had earlier been designated Keewatin. From this it would appear that the term "Coutchiching" was somewhat prior to "Vermilion," and was more fully and precisely defined as to its geological significance. Moreover, the term "Vermilion Lake series" was used earlier by Irving in another sense than that proposed by Professor N. H. Winchell, and in the same Annual Report (Fifteenth) the terms "Vermilion series" and "Vermilion system" are used by Professor A. Winchell, on pp. 192, 195, 196, in another and much more comprehensive, but still undefined, sense.

tinuous, forming a great anastomosing mesh-work, the general strike being always concave to the Laurentian areas which they encircle.

Sometimes, however, where denudation has exposed their deeper portions along anticlinal or synclinal ares, as in parts of the Lake of the Woods and Rainy lake regions, and better in Hunter's island, the formations in contact with the Laurentian granite-gneiss are found to be excessively shattered, and countless numbers of fragments are strewn throughout the mass of the irruptive rocks. The country is well bared, and what is stated is clearly visible on well-exposed continuous rock surfaces. These included detached fragments of the formations overlying the granite-gneiss range in size from pieces a few inches across to immense masses. Their longest diameters are, as would be expected, in the plane of schistosity. Where the enclosing rock is gneissic, the inclusions have usually a constant orientation parallel to the foliation of the gneiss, which also coincides, as a rule, with the nearest edge of the belt through which it breaks, where not too remote from the edge. Other inclusions in the Laurentian have been observed whose derivation from the Ontarian rocks cannot be established. Suggestions as to their origin have been thrown out by the writer in his report on the Rainy lake region.

Along the edges of the belts of the Ontarian rocks, there may frequently be observed, running out from the main belt and in continuous strike with it, tongues of schist which taper more or less gradually and eventually end in points. These also are seen to be immersed and congealed in the granite-gneiss; and many of the larger detached inclusions are doubtless portions of such tongues which have been separated from the main belt by the lowering of the plane of surface truncation by denudation, rather than by actual detachment at the time of disturbance. This would in a large measure account for the fact that the common orientation of the larger fragments, and their parallelism with the edge of the belt, holds for the dip as well as the strike.

Numerous long, attenuated, parallel tongues are also formed at the edges of the schist belts by the injection along the planes of schistosity of portions of the granite-gneiss magma, forming an evenly ribboned alternation which simulates bedding. Its formation by injection is, however, sufficiently apparent. Similar ribboned alternations are described and figured by Barrois * as occurring at the edge of the Cambrian schists of Brittany, where pierced by irruptive granites. The detached inclusions are, also, not infrequently ribboned, parallel to the schist planes, with apophyses from the main area of the enclosing granite-gneiss.

If, at the base of the Ontarian system, we had bedded rocks which on metamorphism gave rise to crystalline limestones, quartzites, etc., we would

* Bull. Soc. Géol. de France, 3me Serie, t. XIV, 1886, p. 833.

have these involved with the Laurentian gneiss, just as the hornblende schists and mica schists are, and intercalations would be produced which would, as in the case of the schists, frequently simulate interbedding of quartzite or limestone, as the case might be, with the gneiss. The deception would, of course, be intensified by subsequent further deformation of the crust by pressure so as to be practically beyond detection, if the clue were not followed up from a starting point where such subsequent dynamic agencies have not obscured the true relationship. This, the writer is persuaded, is the explanation of many of the intimate associations of gneiss and quartzite or limestone, whereby rocks really metamorphic sediments are so involved and welded with rocks of plutonic irruptive origin that they have been taken together as a simple sequence of deposited strata.

In some portions of the Laurentian country, which the attitude of the flanking rocks indicates was once arched over by an anticlinal dome of the latter, there are found patches of schist lying quite flat, or nearly so, upon the granite, showing, in favorable cliff sections, a brecciated or intrusive contact on the under side. These remnants seem to show that the anticlinal dome was flat or very lowly rounded, and that only on the flanks of the Laurentian boss did the strata composing the arch plunge down at high angles.

Significance of Relationship.—Bearing in mind the essential distinctions which exist between the rock formations of the Ontarian and Laurentian systems, both as to their lithological character and their mode of occurrence, and remembering also their relative geographical distribution, the foregoing statement of the relationship which obtains between the two systems leads clearly and unavoidably to this conclusion, viz., that the formations of the Ontarian system at one time rested, as a volume of hard rocks, upon a magma which subsequently crystallized as the Laurentian granite-gneiss; so that the present line of demarkation between the two systems must be regarded as representing the trace of what was once a plane of contact between the then crust and the magma upon which it floated.

This conclusion affords us a conception of the Archean which is ideal in its simplicity and which gives us the key to the raveling of the mystery in which the subject has been involved. The fact that the crust, which constitutes what we now call the Ontarian system, was crumpled while it floated on the magma; the fact that its lower portions were shattered by disturbance so that the magma penetrated the fissures and enclosed detached fragments; the fact that there were currents in the magma which arranged the inclusions in streams and also produced the foliation of the gneiss; the fact of contact metamorphism—all these are incidental and concomitant circumstances of the great essential condition of a crust resting on a magma.

But from the nature of the rocks of the Ontarian system it is clear that

they could not have been deposited upon a magma. There must have been a firm crust presenting a floor upon which they were laid down. That floor, together with portions of the system of rocks which lay piled upon it, has disappeared. That it has sunk down to a zone of fusion and become absorbed by liquefaction in a sub-crustal magma, which later crystallized out as the Laurentian, is the only explanation that is open to us. It follows also that the Laurentian rocks are younger than those of the Ontarian system, as has been before indicated.

Principles of Classification.

The bearing of the facts and conclusions recorded above upon the taxonomy of the Archean is apparent. The argument establishes this cardinal principle in the classification of that great complex of rocks, viz., that its primary subdivision depends upon a distinction of cosmical importance between an older assemblage of altered normal surface-formed strata and a younger assemblage of rocks resulting from the crystallization of a subcrustal magma.

Principles applicable to the Upper Division.—To the upper or Ontarian system the ordinary stratigraphical methods of classification are applicable. The system separates stratigraphically into two great groups. The lower and older, consisting of strata free from volcanic admixtures, so far as has been observed, is the Coutchiching. It resembles in its lithological characters and in its position the Montalban of Hitchcock. The upper group, consisting of rocks which are dominantly volcanic in composition, is the Keewatin. It rests upon the Coutchiching in probable unconformity, the beginning of the period in which these rocks were deposited being signalized by the advent of a widespread and continued volcanic activity. This group falls into line with the Green Mountain series in the position assigned to it by Hitchcock. Other groups may quite possibly be discovered which will swell the volume of the Ontarian system.

Principles applicable to the Lower Division.—In the Laurentian the ordinary stratigraphical principles of classification do not apply, since there are no strata properly so called; and we must seek for a principle appropriate to an assemblage of rocks essentially different in their development and mode of occurrence from all those of the stratigraphical column. The Laurentian is not homogeneous throughout its surface distribution. It is composed of different members or masses, which, while they present wonderfully constant general characters within themselves, are distinct from one another lithologically. A study of the relationship between the masses thus differentiated in space leads us to the chief moment of all geological classification, namely, their differentiation in time; and we have to consider the possibility

of different generations of Laurentian rocks. This possibility presents itself as soon as we familiarize ourselves with the sub-crustal igneous and later formations of the Laurentian.

Different Generations of Laurentian Rocks.—To the writer this conception of different generations has never been more than a possibility till the present year. In his report on the Rainy lake region, two broadly distinct members of the Laurentian were distinguished, lithologically and on account of their systematic relative distribution, as the "peripheral zone" and "inner nucleus" of the Stanjikoming area, the former being composed chiefly of hornblende-granite and syenite-gneiss, and the latter of very quartzose biotite-gneiss. The relationship in time between these two rock masses remained indeterminate. During the past summer, however, he has been able to establish, in the Hunter's island region, chronologically distinct generations of Laurentian gneisses. In that region there are two broadly distinct members of the Laurentian, analogous petrographically and in relative distribution to those of the Stanjikoming area. Below the Keewatin rocks there is a great mass of hornblende-granite-gneiss, which presents an irruptive or intrusive contact against them. Towards the central part of Hunter's island this hornblende-granite-gneiss is pierced by an enormous irruption of biotite-granite, which is sometimes very distinctly gneissic and sometimes quite undifferentiated in structure. In texture it varies from fine-grained, almost micro-granitic, to a moderately coarse granite. This biotite-granite-gneiss traverses the hornblende-granite-gneiss in innumerable clearly defined dikes cutting it in all directions, and holds innumerable included blocks of the same rock. It comes up from beneath the hornblende-granite-gneiss, and is unquestionably of later age.

Thus we have in this area at least two distinct generations of Laurentian rocks, both the result of the crystallization of a sub-crustal magma. At the time of the second generation the rocks of the first generation constituted the lower portion of the crust.

It is upon the recognition of facts of this order that an intelligible and profitable classification of the Laurentian rock masses and the geological events which they represent must be established.

Other Conditions considered.—The relationship which has been found to obtain between the upper and lower Archean leads, as has been said, to a conception which is at once grand and simple. So long as we confine ourselves to regions like that northwest of Lake Superior, where no great complications have been introduced by post-Archean crust-crumpling agencies, it affords a full explanation of all the phenomena of Archean geology.

There is a possible simpler case which would still present the essential conditions of the relationship in question; *i. e.*, the case in which the sub-

crustal magma might be irrupted within the overlying crustal rocks without the intense folding of the latter. Here we should expect to find a less pronounced alteration, due only to the proximity of the magma, and an absence of those phases of metamorphism which accompany the rock shearing, crushing, and stretching due to dynamic agencies. In the common case, where the upper crustal rocks are folded, varying phenomena would also be observed according as the folding took place before the fusion which produced the magma immediately beneath the crust or while the latter was floating upon the magma.

There are also more complicated cases which are doubtless common. These are due to the superimposed action of crust-crumpling, rock-shearing, strata-squeezing forces subsequent to the establishment of the Archean conditions in their primal simplicity. These are possibilities which must be borne in mind in attempts to apply the theory here advanced to the Archean in other regions. It is easily conceivable that had the country northwest of Lake Superior been subjected to extensive deformation in post-Archean times, the evidence whereby the irruptive character of the Laurentian has been demonstrated might have been entirely obscured, and the true relationship might have remained unsuspected, as appears to have been the case in better known regions.

Similar Observations elsewhere.

In various parts of the world observations have been recorded which show that the phenomena arising from the irruption of a local or general subcrustal magma through an overlying crust, and the consequent development of a complex of gneissic igneous rocks and metamorphic strata, are not peculiar to the region studied by the writer.

MacFarlane* long ago described and figured good evidence of the irruptive character of the Laurentian of the northeast shore of Lake Superior; but, in accordance with the views of the extreme plutonic school, he regarded the whole complex of intrusive and intruded rocks as the first crust of the earth, and the angular fragments of hornblende schist as earlier separations from the same magma as that which crystallized into the Laurentian granite or syenite-gneiss.

Mr. Frank Adams, who has been for some years past engaged in a study of the Laurentian of the Province of Quebec, north of the St. Lawrence, says—

"The unexpected fact was ascertained that the so-called massive and stratified varieties of this rock [anorthosite; hitherto regarded as upper Laurentian and meta-

* Geological Formations of Lake Superior. Canadian Naturalist, N. S., Vol. III, 1867, p. 177.

morphic] are in reality only different portions of one and the same mass. * * * As a result of this summer's work, I think it may be safely concluded that the rocks comprising the principal area of anorthosite above referred to, as well as most, if not all, of the smaller areas, are of eruptive origin." *

He confirms this in his summary for 1888 in the following words:—

"All the areas of anorthosite now known to occur in the district have been examined, and mapped, and have proved to be either eruptive masses cutting through the gneisses, or masses interstratified with the latter, but probably still of eruptive origin." †

Callaway has shown, in his paper on the granitic and schistose rocks of northern Donegal, that the granite-gneisses of that region, which have been regarded as Laurentian and which correspond closely in lithological characters and mode of occurrence with the Laurentian of Canada, are really irruptive through older rocks, which must have arched them over, and present all the evidences of irruption which have been adduced by the writer in support of the irruptive origin of the Laurentian northwest of Lake Superior. He thus states his conclusions:—

"1. The granite rock of northern Donegal, originally supposed to be the result of the metamorphism of sediments, and recently referred to the Laurentian system, is a true igneous granite, as seen in its intrusion into the adjacent schists, in its inclusions of masses and fragments of other rocks, and in its metamorphic action on limestone in contact. 2. This granite is distinctly foliated, the gneissic structure being caused by lateral pressure, * * * 3. The granite is intrusive in a thick group of quartzites, quartz-schists, hornblendic, micaceous and talcose (?) schists, and crystalline limestones, called the *Kilmacrenan series*. These rocks are truly crystalline, but usually thin-bedded and fine-grained. 4. The crystalline schists are bounded on the east by a semi-crystalline series, consisting of quartzose grits and itacolumites, quartzites, crystalline limestones, compact dolomites, phyllites, interlaminations of grit and schistose matter, and finely foliated micaceous schists." ‡

These conclusions as to the irruptive origin of the gneiss are confirmed by later observations of the same investigator on the Galway gneiss. §

In the pre-Cambrian or Archean of Brittany, Barrois recognizes the irruptive character of the gneisses which correspond to our Laurentian. He says—

"Ces gneiss alternent avec des lits interstratifiés de micaschistes et d'amphibolites, et passent à des granites gneissiques qui les pénètrent à la façon d'une roche éruptive. L'ensemble des *gneiss et micaschistes granitiques* avec granites gneissiques rappelle par ses caractères lithologiques *l'étage dimétien*, proposé par M. Hicks, dans le pays de Galles, le gneiss fondamental d'Ecosse, certains gneiss laurentiens du Canada,

* Geol. Survey of Canada, Summary Report for 1887 and 1888, 1889, p. 27A.
† Ibid., p. 85A.
‡ Quart. Jour. Geol. Soc., Vol. XLI, 1885, p. 239.
§ Quart. Jour. Geol. Soc., Vol. XLIII, 1887, p. 517.

* * *. Ils [micaschistes] y alternent avec des lits subordonnés de gneiss à grains fins, d'amphibolites, de chlorito schistes, de schistes micacés, et comprennent des masses interstratifiées de diorites et de granulites, d'origine éruptive. Ces roches subordonnées forment avec les micaschistes, dans lesquels elles sont injectées, de longues bandes parallèles, * * *."*

Newton's description of the geology of the Black Hills of Dakota † leaves little room for doubt but that the rocks which he calls Archean correspond to the upper Archean or Ontarian system of central Canada, and that his irruptive granite, though not described as foliated, is the analogue of the commonest phase of the Laurentian. The same relationship holds between the two rock systems in both regions, and many of the Laurentian granites are devoid of foliation.

Geognostical Equivalents of the Archean.

In assemblages of rocks of indeterminate or post-Archean age complexes of gneissic irruptive rocks and older metamorphic strata of clastic or volcanic origin are now well known. These cannot be spoken of as the geological equivalents of the Archean complex on account of their diverse age, but may be referred to as its geognostical equivalents, since their development appears to depend upon universal sub-crustal conditions, which are to a large extent independent of geological age.

McMahon,‡ in his studies of the great "central gneiss" formation of the Himalaya mountains, has demonstrated clearly that the formation is not, as was long supposed, the Archean basement upon which the Paleozoic sediments were deposited, but is an irruptive mass breaking up through the Silurian and later rocks, altering them, holding detached fragments of their strata, and being injected within the strata. Speaking of this formation, which he calls gneissose granite, he cites the following evidences in proof of its irruptive origin: 1. The granite has produced a certain amount of contact metamorphism on the rocks touching it. 2. Tongues and intrusive veins have been sent from the granite into the adjoining rocks; in other places the granite appears in sheets between the beds of the sedimentary rocks at some distance from the junction of the latter with the main mass of the granite, and in some cases these sheets or dikes have cut through the beds and passed from one horizon to another. 3. The main mass of the granite appears at different geological horizons.§ 4. The granite contains

*Structure Geologique du Finistère. Bull. Soc. Geol. de France, 3me Serie, t. XIV, 1886, p. 657.

† Report on the Geology and Resources of the Black Hills of Dakota. By Henry Newton and Walter P. Jenney, Washington, 1880, pp. 45–80, 220–222.

‡ Geol. Survey of India, Records, Vol. XVIII, Part 4, 1884, p. 168; ibid., Vol. XVIII, Part 2, 1885, p. 79. Geol. Mag., N. S., Decade III, Vol. IV, 1887, p. 212.

§ As it does when it comes at one place against the Keewatin and at another against the Coutchiching in the Rainy lake region.

veins similar to those caused by shrinkage on cooling in granite of admittedly eruptive origin. 5. It contains fragments of slates and schists imbedded in it. He also states that the evidence afforded by the study of thin slices confirms the conclusion arrived at by the stratigraphical evidence, and gives a summary of the microscopic evidence.*

The very able and precise descriptions by Barrois † of the various granitic irruptions which have affected Brittany at different ages from the pre-Cambrian up to the Carboniferous show beyond question that not only in Archean times, but at various subsequent periods were the conditions which characterize the Archean of Canada reproduced. He describes particularly the "granite gneissique," demonstrates its irruptive origin, and notes not only the contact metamorphism, but also the injection of these rocks "en filonnets minces et répétés" within the encasing schists. His descriptions and figures of repeated injections of granite within the schists, so as to produce an alternation simulating bedding, closely corresponds with the contact phenomena described by the writer as observed between the Laurentian and Keewatin on the Lake of the Woods, the interpretation of which is entirely in accord with that of Barrois, though questioned by Professor A. Winchell.‡ It would appear that just as in Hunter's island, northwest of Lake Superior, we have two generations of Laurentian rocks from a sub-crustal magma, so in Brittany there have been several generations of similar rocks breaking through the overlying crust, extending in time as late as the Carboniferous.

In Norway Kjerulf § places the "Gebanderte granit, oder gneisgranit" with the eruptive rocks, and states that in numberless places such rocks break through the strata of the grundgebirges, and also, indeed, through the Bergenschiefer in which Reusch has since found Silurian fossils.|| In the greater part of Norway he says (translated freely) ¶—

"What was formerly recognized as gneiss must on the map be now designated as granite. The reason why the older observers assume it to be gneiss is the granular banded structure, which we must distinguish from the appearance of bedding. On older maps are shown also other great regions in which the dip and strike of the beds is given, an attribute which they do not in reality possess; and the reason for this lies in the confounding of foliation with bedding. * * * The rock, according to the old conception, is granite when no bedding occurs in it. The modern view, which had already been announced by Delesse, says: 'En réalité c'est [le gneiss granit] seulement une variété du granit, qui est veinée et qui parait avoir été gênée dans sa cristallisation.' " **

* Geol. Mag., loc. cit.
† Bull. Soc. Geol. de France, 3me Serie, t. XIV, 1886, pp. 655–898.
‡ Geol. Survey of Minnesota, Fifteenth Annual Report, 1886, p. 201, § 5.
§ Die Geologie des Süd. und Mit. Norwegen, Bonn, 1880, p. 237.
|| Fossilien Führenden Schiefer von Bergen, Leipsig, 1883.
¶ Op. cit. p. 282.
** Delesse, Etudes sur le Metamorphism, 1861.

The syenites of the southeast coast of Norway, also, which have been studied particularly by Brögger, and which are irruptive through fossiliferous Silurian and Devonian strata, are eminently gneissic in places. They are indistinguishable in this respect from the more distinctly foliated varieties of our Laurentian gneiss.

Lehman's masterly work * on the rocks of Saxony and other geologically similar regions has clearly established that many of the gneisses of central Europe are irruptive in their origin.

The foliated gabbros or gabbro-gneisses of the Lizard are regarded as eruptive by such eminent observers as Teall † and McMahon,‡ though they differ as to the precise mode of the development of the foliation.

Harper § has shown that the "granite and gneissic granite" of Larn, Caernarvonshire, which was formerly held to be Archean, is in reality irruptive and of more recent age than the Upper Arenig strata:

> "The actual contact of the two rocks is easily found, and the granite is seen to send out little tongues between the laminæ of the shale. Specimens of the latter rock, indurated and firmly adhering to the granite, may be obtained. * * * The shale is clearly altered and exhibits little spots and nodules supposed to represent the incipient development of chiastolite. Another quarry, well within the boundary of the granite, shows entangled masses of baked shales."

In a paper submitted to the International Geological Congress at its London session ‖ in 1888, the writer quoted Dr. G. M. Dawson ¶ at some length to show how entirely the conditions which obtain between the Triassic rocks of the west coast and the younger subjacent irruptive granite are analogous to those which obtain between the rocks of the upper Archean or Ontarian system and the Laurentian granite gneiss. Dr. Dawson's account of the history of geological events in that region in post-Triassic times confirms the correctness of the writer's interpretation of the Archean of central Canada.

The interesting geognostical equivalent of the Archean on the Pacific coast is paralleled on the Atlantic coast by the great irruption of "gneissic granites" which in post-Cambrian times, possibly as late as the Devonian, have broken up through the Cambrian slates and quartzites.** These "gneissic granites" are indistinguisable from many of the Laurentian gneisses.

* Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine, Bonn, 1884.
† Origin of Certain Banded Gneisses; Geol. Mag., N. S., Decade III, Vol. IV, 1887, p. 484.
‡ On the Foliation of the Lizard Gabbro; ibid., p. 74.
§ Quart. Jour. Geol. Soc., Vol. XXXIV, 1878, p. 442.
‖ Etudes sur les schistes cristallins, p. 66.
¶ Geol. Survey of Canada, Annual Report, 1887, Part B, pp. 11–13.
** The Lower Cambrian rocks of Guysborough and Halifax Counties, N. S. By E. R. Faribault; Geol. Survey of Canada, Annual Report, 1886, Part P, p. 129.

The Argument from Analogy.

These references and quotations by no means exhaust the literature of the subject. They are taken mostly from very recent writings, and much to the same effect might be quoted from the older geologists, such as Von Cotta, Neumann, Darwin, Delesse, and others, who have insisted on the irruptive character of gneissic rocks or have regarded gneiss as but a differentiated variety of irruptive granite. But enough has been adduced to show that the writer's interpretation of the Archean geology of central Canada, in so far as it depends upon the irruptive nature of the Laurentian gneisses, is not without the strong support of many analogies.

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STRUCTURE AND ORIGIN OF GLACIAL SAND PLAINS.

BY WILLIAM MORRIS DAVIS OF HARVARD COLLEGE.

(*Read by title before the Society December* 27, 1889.)

CONTENTS.

External Form and Internal Structure.—Plains of stratified gravelly sand, half a mile or more in diameter, standing mesa-like above the adjacent valley ground, are common in many parts of New England. They lie on striated ledges and till, and hence are at most not older than the closing stages of the latest glacial epoch. Their distinct marginal slopes give no indication of more than a small measure of erosion, and hence their present form may be taken as essentially equivalent to their initial constructional form. They are well stratified throughout, and this, along with their definite marginal slope, indicates them to be deposits made in bodies of standing water.

The general surface of these sand plains is very even, but fails of being level by reason of a gentle slope, generally to the south, of ten, twenty, or thirty feet to the mile. Their margins are in most cases well defined, having slopes of from 10° to 30°. They present two very distinct forms of outline, illustrated in plate 3. The northern quarter of the perimeter possesses a number of strongly concave curves, descending by steep slopes to kettle-hollows, often holding swamps or ponds; and the cusp-like points between these curves extend northward into a group of gravelly ridges and sandy

hillocks—eskers and kames. The other three-quarters of the perimeter, turned to the south, is even more strongly characterized by a number of convex lobes and sub-lobes, separated by re-entrant interlobate hollows.

The internal structure of the plains, where revealed by railroad cuts and sand pits, consists in greatest part of obliquely deposited beds of sand, or occasionally of sandy gravels, dipping towards the lobate margin at an angle of from 20° to 25°; but these are covered by gravelly or sandy cross-bedded horizontal layers to a depth of from five to fifteen or more feet, and the thickness and coarseness of this cover appears to increase towards the esker and kame margin.

Hypothesis of Origin.—In view of these facts of form and structure, it is difficult to find any explanation for our sand plains other than the one generally current, which regards them as delta-like deposits of sand and gravel, washed in the closing stages of the last glacial epoch from the irregular front of the melting, stagnant ice-sheet into bodies of water that bathed its edge. Before looking further at the facts, let us extend this hypothesis as far as possible to its consequences, and then test its correctness by the complication of correspondence between deduction and observation.

Deductive Extension of the Hypothesis.—The former existence of an ice-sheet over New England is accepted as evidence that is entirely independent of the occurrence of sand plains. The ice-sheet is now gone; and between the times of its greatest thickness and fastest motion and of its entire disappearance it must have been reduced to a thickness at which motion was impossible; then it lay passive and stagnant, as Chamberlin has pointed out, for the remainder of its existence; during this time it must have melted irregularly, presenting a very uneven, ragged front, from which residual blocks may have been frequently isolated; and it must have endured longest in the valleys, where it was thickest, not only by reason of its greater depth, but also because its surface there, where motion had been fastest and longest maintained, must have been higher than on the hills—this being homologous with the variation in the thickness of a Swiss valley glacier from middle to sides.

A melting ice-sheet must have frequently embarrassed the drainage of the surface on which it lay; ponds would accumulate in hollows and valleys sloping towards it, as Upham and McGee have indicated, and after standing for a time at a level determined by one line of overflow they must have suddenly fallen or drained away as new outlets were opened by the melting of the ice, thus causing active floods. Near the coast a moderate (relative) depression of the land seems to have brought standing sea water against the ice some ten or twenty miles inland from the present shore-line.

Wherever active, drift-laden streams ran from the melting ice into standing water at its margin, their velocity must have been checked and all but

the finest part of their load dropped. The channels leading strong streams to the margin might receive esker-like deposits of coarse gravels and sand irregularly deposited; the open spaces near the ice margin, containing waters of gentler movement, would become choked with kame-like mounds of finer sand; and where streams of either class ran from the ice to the water in front of it, sand deltas must have grown with greater or less rapidity. Their growth would be in three directions. They would grow forward by continued addition of oblique layers to their sloping front; as the front advanced they would slowly grow upward by the addition of essentially horizontal layers, after the fashion of ordinary deltas, in order to maintain a gentle surface slope from head to front; and as the ice melted away, the space that it evacuated at the head of the delta would be more or less completely filled by a backward growth at that part. If the feeding streams came from beneath the ice they must needs rise to flow over the delta surface to its front, and hence the backward growth at the head must have been at such points in the form of up-hill deposition. These three classes of deposits may be called fore-set, top-set, and back-set beds, shown in fig. 1; and it is

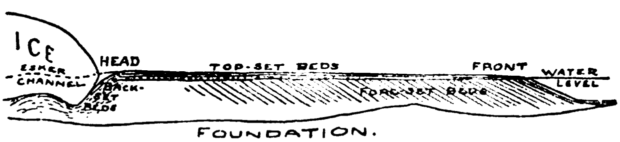

FIGURE 1.—*Ideal Longitudinal Section of a Sand Plain.*

manifest that the ratio of fore-sets to back-sets must be the same as the ratio of the forward growth of the delta to the backward melting of the ice.

When re-arrangement of glacial drainage leads the feeding streams away to some other outlet, and when later melting or elevations of the land allows the marginal waters to drain away, the deltas previously formed stand up somewhat above the adjacent surfaces; the steep, concave outlines of the head of a plain, with its feeding eskers, kames, and kettles, mark the irregular margin of the melting ice; and the convex lobes of the front of a plain mark the growing front of the delta.

Verification of the Hypothesis.—The general correspondence of the foregoing deductions with the facts is a sufficient assurance that our search for explanation is in the right direction; but certain facts of structure need reexamination in the light given by our theoretical suggestions. Is there any direct indication that the front of the plain grew forward by down-hill deposition, while the head grew backward by up-hill deposition? The fine cross-bedding frequently characteristic of both the fore-set and back-set beds leaves no doubt on this point, when its significance is clearly perceived; and for this a brief digression is needed.

Evidence from Cross-bedding.—Normal oblique deposition may be typified in fig. 2, from which it appears that every bed presents a convex upper portion, *a b*, and a concave lower portion, *c d*, joined by a tangent, *b c*. When a change of current carries away the upper part of such a deposit above the line *e f*, the upper convex curve is destroyed and only part of the tangent and the concave curve remain; and when a later change brings additional deposits, these lie with their concave lower curves tangent to the surface of truncation of the earlier beds. It does not appear that the forms

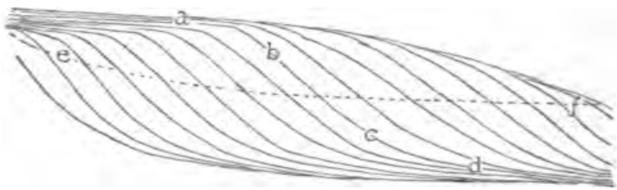

FIGURE 2.—*Ideal Section of Cross-bedding.*

and relative position of such beds would be changed, whether they are laid down on a descending or an ascending surface; the only essential condition of their growth is the presence of a stream of varying power and load, but on the whole of greater load than power. Back-set and fore-set beds should, therefore, turn the concavity of their cross-beds in the direction of the stream that formed them—that is, in the direction from the head to the front of the plain.

Figs. 3 and 4 are from sketches made of the back-set beds at the head of a sand plain in Newtonville, and of the fore-set beds at the extremity of a

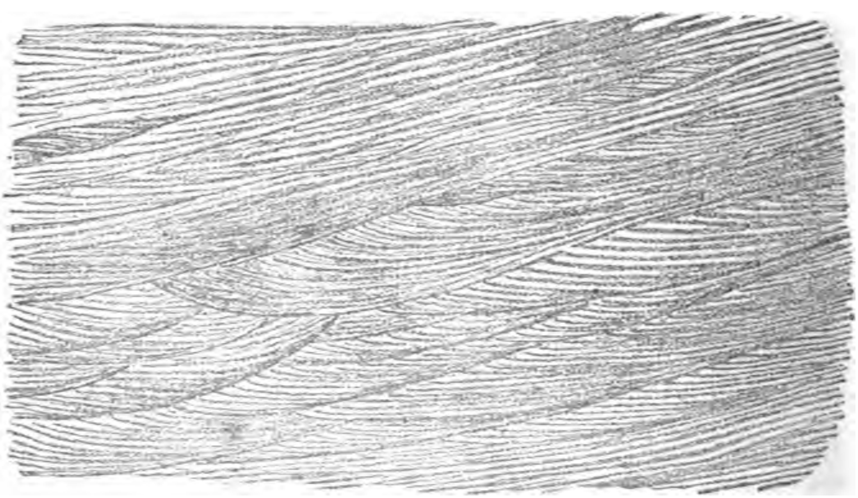

FIGURE 3.—*Cross-bedding at the Head of a Sand Plain.*

frontal lobe of a sand plain near Wakefield, both in eastern Massachusetts. It is manifest that both were built by a stream moving to the right in the figure. This corresponds to the direction from head to front of the plains, and indicates that the back-sets were built by an ascending stream, rising

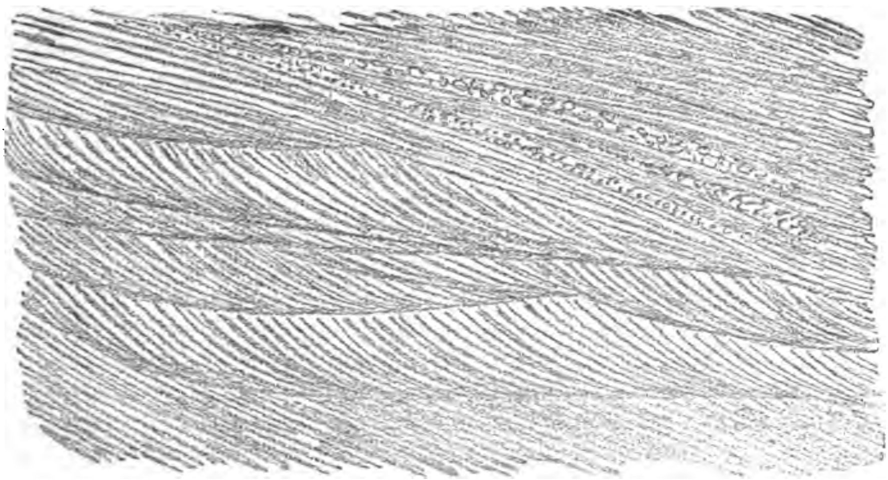

FIGURE 4.—*Cross-bedding at the Front of a Sand Plain.*

from beneath the ice to the top of the delta plain, while the fore-sets were built by a descending stream, flowing from the plain into the water at its front.

Ratio of Sand-plain Growth to Ice Melting.—The ratio of fore-set and back-set beds is of interest, for, as already stated, it indicates the ratio of the forward growth of the delta to the backward melting of the ice. The sections thus far examined do not furnish final numerical results; but enough has been seen to make it clear that the fore-sets are from ten to forty or fifty times as extensive as the back-sets, and from this it appears that the melting of the ice was slow compared to the growth of the delta plain.

Origin of Depressions in Sand Plains.—This conclusion is of value in explaining the pits, kettles, and irregular depressions that frequently interrupt the otherwise level surface of the plain. The theory has long been current that these pits were the sites of isolated blocks of ice, around which the sands of the plain were deposited; but it has also been currently objected to such an explanation that it involved an improbable and unproved rapidity of sand-plain growth. The conclusion just gained from the ratio of the fore-sets to the back-sets overcomes this objection. No satisfactory section of the slopes of a pit has, however, yet been found to give more direct evidence on this question.

Local and Temporary Growth of Sand Plains.—A corollary of the rapid growth of the delta plains compared to the retreat of the ice is, that the growth of delta plains was a local, temporary, and spasmodic operation; for if it had been general, persistent, and continuous, the plains must have been of vastly greater extent than we find them. It is true that, in front of the great terminal moraines, there is a wide-spreading sand plain; but here, however intermittent its growth may have been, its locus of deposition was maintained within narrow limits for a long time. Such was not the case with the sand plains that are dotted over New England; they were formed as the ice was on the whole retreating; and yet, in spite of their rapid advance compared to its retreat, they occupy but a small part of the country—not more than a twentieth and probably much less. The standing water in which they were built was seldom completely filled up, for their frontal slopes commonly descend into meadows, often of large extent.

In searching for the cause of the local character and brief duration of their growth, we can hardly expect to find it in the cessation of outward drainage from the retreating ice-sheet, or in the discharge of sand-laden streams at one time and clear-water streams at another. A more probable explanation looks to the variation in the point of discharge of the sub-glacial streams. The larger rivers were presumably fixed, but the smaller ones must have frequently changed their courses. When they discharged into valleys sloping away from the ice front, the valleys became clogged with gravel and sand, stretching far down stream, to be terraced later on; but when they discharged into valleys of northward slope they were ponded back, and their deposits were concentrated in their deltas, until a change in the point of escape was made, when similar processes went on elsewhere.

It is not uncommon to find the frontal lobes of a sand plain lying on kame mounds and esker ridges of earlier origin, as at the southwest front of plate 3. The same relation must often occur within the plain. It finds illustration in a valuable section on the Belt Line of the Boston and Albany railroad, a mile south of Auburndale, which shows the triangular outline of a stony esker buried in the fore-set sand beds of a plain. The edge of the ice must have been south of this point when the esker was formed, and north of it when the sand plain was built; and between these two dates there must have been a time of very small deposition hereabouts, for back-set beds are wanting.

The coarse, gravelly character of the top-set beds of sand plains is a natural result of the continued selective process that must have gone on over the surface during their deposition. The gravelly beds represent the residual material left in the beds of shifting and branching delta streams, the greater part of the material of finer texture having gone forward to build out the front of the delta. In the same way the coarse, water-worn material of the eskers, with its frequently loose arrangement and very imperfect stratifica-

tion, indicates that here also much more detritus was carried along than was laid down. The sand-plain front was the goal at which most of the detritus stopped, and hence its rapid growth. The clay beds that we should expect to find as the final deposits of the glacial streams probably occupy the meadow bottoms in front of the sand plains; but as yet no sections clearly manifesting the relation of the clay to the sand plains have been found.

Sand Plains generally formed in local Bodies of Fresh Water.—Near the coast, and up to an elevation of fifty or a hundred feet above present sea level, in eastern Massachusetts, the water in which the sand plains were built appears to have been ocean water; but the amount of submergence thus surmised has not yet been fully worked out. Further inland, where plains are found up to altitudes of a thousand or more feet above sea level, I think the water in which they accumulated was fresh water, temporarily ponded by the ice front. The reasons for this opinion are as follows:

The ice of the last glacial epoch appears to have melted off of the country first in the southern and later in the northern part of its area, producing a general northward migration of the locus of sand-plain formation. Accepting the generally current idea that the depression of the land diminished as the ice retreated, it follows that the sand plains of later date should be of less elevation above present sea level than the earlier ones, if they were all deposited in ocean water; and this is not the fact. The sand plains of the interior and northern part of New England, which must have been built at a relatively late stage of ice melting, are of distinctly greater elevation above existing sea level than those near the coast, which must have been built at an earlier date. The interior sand plains are therefore regarded as having been accumulated in local and temporary ponds, determined by the ever-changing relation of the rock and drift topography to the frontal margin of the retreating ice. Otherwise it would be necessary to suppose that the submergence of the land increased as the ice melted away; and while this is manifestly not to be regarded as geologically impossible, it does not appear to be accordant with the general results of glacial study thus far obtained.

Relation of Sand Plains to other Glacial Deposits.—The relation of glacial sand plains to two other similar forms of late or post-glacial deposits may be briefly mentioned. In many cases the streams from the ice ran down open valleys, and not into ponds of standing water. In such cases the valleys were commonly clogged with flood-plain deposits of sand and gravel, often of great extent. These are unlike the glacial sand plains in having no definite frontal slope, and hence in wanting also the steep-dipping fore-set beds, of which the frontal slope is the external expression. The flood-plains are indeed merely extended illustrations of what I have called the top-set beds of the sand plains; but their connection with the back-set beds, which theory leads me to suppose must exist, has not been traced out. The original flood-plain, now the upper terrace, of the Merrimac, as described by Upham, in

New Hampshire, is a large example of this kind. The sand and gravel plain of Rock river in southern Wisconsin appears, from its descriptions and from the brief sight that I have had of it, to be another. As a natural consequence of the change from the conditions of their formation to their present conditions it follows that valley flood-plains are now commonly terraced by the streams that formed them, while sand plains proper are nearly always avoided by streams.

The other deposits that simulate the glacial sand plains are the stream deltas, formed normally in the ponds that temporarily fringed the ice front. Following Upham again, I have been led to an excellent illustration of these deposits in the Contoocook valley in southern New Hampshire, where a lake of considerable size was ponded back by the ice. The streams that enter this valley formed deltas of several acres in extent when they entered the lake, and these deltas are now found perched up, at an accordant altitude, on the steep hill-slopes that enclose the valley; and at the same level, stony benches, sandy beaches, and linear bars may easily be traced for many miles. Emerson has described similar stream deltas in the Connecticut valley. Like the valley flood-plains, these normal stream deltas are now commonly cut through by the streams that made them. Like the glacial sand plains, they present strongly marked frontal slopes, but, unlike them, they are built out from a solid land support, against which they still rest, while the support from which the glacial sand plains grew has vanished away.

Points needing further Observation.—The search for structural features of sand plains (in which I have been aided by several students, especially Messrs. Ropes and Stone, of the class of 1889 at Harvard College, and by Mr. Gage, a special student) has not yet discovered any examples of the superposition of sand plain beds on their foundation of till; the statement already made to the effect that such is the order of deposit is based partly on the not infrequent protrusion of glaciated rocky knobs above the surface of a plain, and partly on the apparent overlapping of till slopes by sand-plain lobes. Nor has the point of change from back-set to fore-set beds been found in any cut yet visited; but the occurrence of fore-set beds close up to the head of several plains shows clearly enough that very little room can be left for the back-sets. No section of the slopes of a pit within the plain has yet been discovered; the nearest approach to this was the finding of a small buried pit about fifteen feet in diameter—that is, a pit that had been filled by subsequent deposit of top-set beds; this showed distinct down-faulting of the marginal beds, as if some local support had been withdrawn from below them, and this is interpreted as indicating the melting away of a small ice block, after some of the top-sets had been spread over it, and before the building of the plain had ceased.

When our search has been carried further, we shall attempt a fuller statement of the case, with detailed illustration of many sections and various sand plains.

A REPRESENTATIVE GLACIAL SAND PLAIN.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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THE PRE-CAMBRIAN ROCKS OF THE BLACK HILLS.

BY C. R. VAN HISE.

(*Read by title before the Society December* 28, 1889.)

CONTENTS.

PREVIOUS WORK.

Apparently Dr. Hayden * and Professor N. H. Winchell † were the earliest geologists to visit the Black Hills of Dakota; the former while engaged in his extended surveys in the Northwest, the latter as the geologist of General Custer's expedition of 1874. The works of both in this region were no more than reconnaissances, and the pre-Cambrian rocks received comparatively little attention.

One of the consequences of these preliminary trips and exaggerated reports as to the richness of the hills in gold was a systematic survey of the

*On the Geology and Natural History of the Upper Missouri, F. V. Hayden: Trans. Am. Phil. Soc., 1861, pp. 218. This was Dr. Hayden's most complete account of the Black Hills region, and sums up the results of his previous reports.

†Geological Report on the Black Hills of Dakota, with map, by N. H. Winchell. Contained in "A Report of a Reconnaissance of the Black Hills of Dakota," made in the summer of 1874, by William Ludlow; 1875, pp. 21-66.

area by the Rocky Mountain division of the United States Geological Survey under the direction of Major Powell. This work was entrusted to Messrs. Henry Newton and Walter P. Jenney—Newton as geologist and Jenney as mining expert. Newton's death occurred before his report was ready for the printer, and it was edited by Mr. G. K. Gilbert. The large monograph * which appeared as the result of Newton and Jenney's field-work contains, besides their reports, chapters by Whitfield, Caswell, Gray, and Tuttle upon their respective specialties. From the time of its appearance this work has been the great authority on Black Hills geology, and of its excellencies, which are due alike to the ability of Newton and the skill and insight of the editor, all later geological visitors to the Black Hills have spoken.

Work in this region subsequent to that of Newton and Jenney has been in the nature of various brief visits by different geologists for particular objects. Devereux † speaks of the geology of the Black Hills in connection with the origin of certain gold ores. Emmons ‡ gives a brief geological sketch of the region in the Tenth Census reports. Blake, § in Mineral Resources of the United States, makes a few remarks on its geology. The most important articles from a geological point of view, however, which have appeared since Newton and Jenney's monograph are by Crosby || and Carpenter.¶ Their field-work was done together, and their articles have many points in common.

Scope of Paper.

The present paper is based upon a visit to the Black Hills during the summer of 1889. Like those who have preceded me, since the time of Newton and Jenney, my object was specific rather than general in its nature. In the field-work I had the assistance of Professor C. W. Hall. I am also indebted to Professors F. R. Carpenter and William P. Headden, and Mr. Theodore Kuntzen, all of the Dakota School of Mines, for important information as to localities and roads, while Professor Headden kindly made an investigation as to the relations of the Cambrian sandstone and the granite in the vicinity of Hayward. No attempt was made to study the formations of the Hills or to revise the conclusions that had been before reached, with the exception of the pre-Cambrian rocks. The so-called Archean core, using the term of Newton, was traversed from north to south and east to west.

* Report on the Geology and Resources of the Black Hills of Dakota, with atlas. By Henry Newton, E. M., and Walter P. Jenney, E. M., 1880, pp. 566.

† The Occurrence of Gold in the Potsdam Formation, Black Hills, Dakota; Walter B. Devereux: Trans. Am. Inst. Min. Eng., Vol. X, pp. 465–475.

‡ Geological Sketch of the Black Hills of Dakota; S. F. Emmons: Tenth Census of the United States, Vol. XIII, Precious Metals, 1885, pp. 89–94.

§ Tin ore in the Black Hills of Dakota; W. P. Blake: Mineral Resources of the U. S., 1883–'84, pp. 602–613.

|| Geology of the Black Hills of Dakota; W. O. Crosby: Proc. Bos. Soc. Nat. Hist., Vol. XXIII, 1888, pp. 488–517; Quartzites and Siliceous Concretions; W. O. Crosby: Tech. Quart., May, 1888, pp. 397–407.

¶ Preliminary Report of the Dakota School of Mines upon the Geology, Mineral Resources, and Mills of the Black Hills of Dakota; Franklin R. Carpenter and H. O. Hoffman. 1888, pp. 171.

Very numerous specimens were collected, from which thin sections have been made. The objects of the study were, to ascertain the basis upon which these rocks are divided into two series; to get, if possible, some idea of their structure; to compare them with those of other pre-Cambrian areas; and, finally, to attempt to get at the genesis of the crystalline schists there exposed.

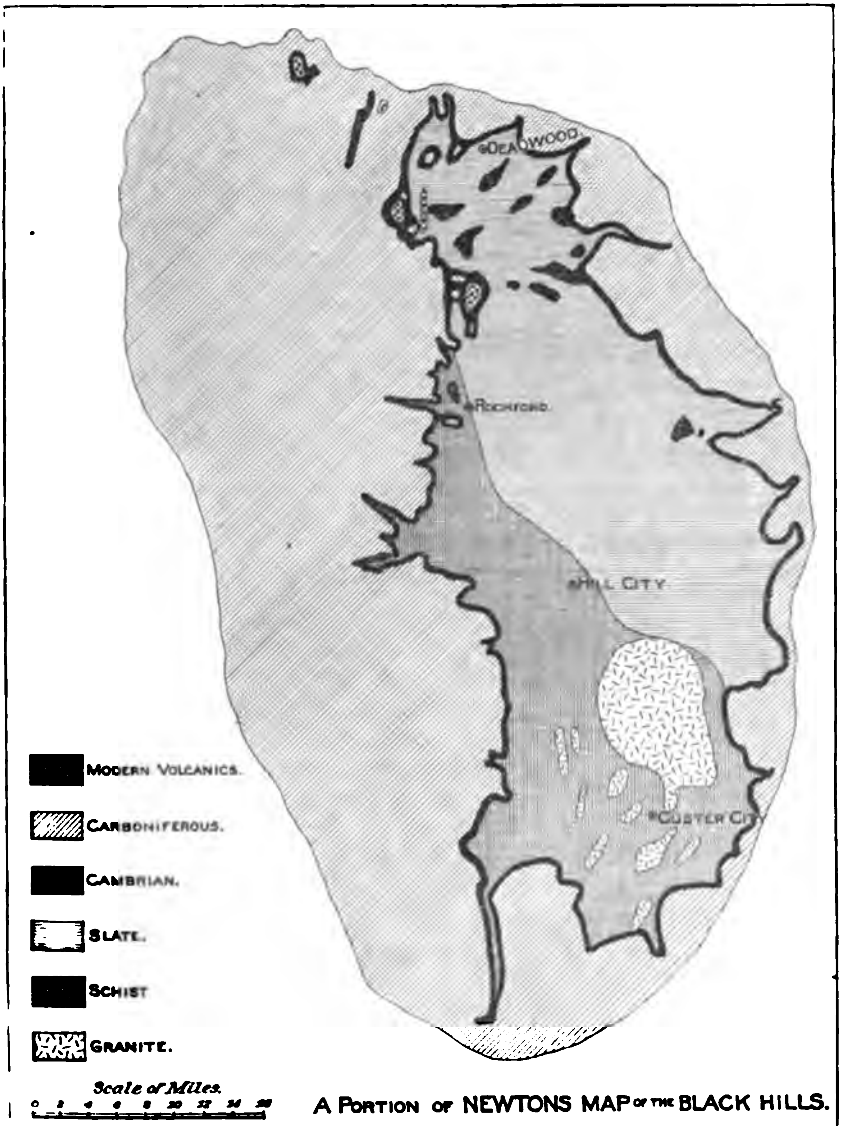

FIGURE 1.

Distribution and Structure of the Rocks.

As shown by the accompanying map (fig. 1), copied from Newton's report, the pre-Cambrian rocks are divided into an eastern or slate and a western or schist area. Within the schist area are located several detached masses of granite, one of considerable size, the highest peak of which is the culminating point of the hills. The slates and schists are described by Newton as vertical and as having in general a strike approximately north and south, or a little west of north and south of east, with wide local variation. Although Newton and Jenney looked for proof of discordance between their slate and schist series, they found no positive evidence of it, although at one obscure locality Jenney thought he saw such indications.* No evidence that the schist or slate is folded was found, and it was thought their combined thickness is very great, being represented by the surface exposure of the pre-Cambrian core in an east and west direction. The following paragraph is from Newton:

"Our examination brought to light no evidence of the duplication of any parts of the Archean rock system. If the slates or the schists were folded upon themselves and afterwards worn away, so as to leave two or more parallel outcrops of the same beds, the folding must have been confined to the homogeneous soft beds; and the presumption is that no such folding took place within the area exposed in the hills. The whole system of vertical beds, with a width of about twenty-five miles, is believed to retain its original relation of parts. It has not, of course, its orignal position, for the same great process of change which has produced its metamorphic structure has turned it bodily on edge and either broken away or eroded away its upward continuation; but it is probable that the system presents the clays and shales and sandstones from which it was produced by metamorphism in the same order in which they were originally deposited." †

The enormous thickness of sediments which this explanation requires was realized by Newton and Gilbert, and was evidently regarded as a fact against its correctness. No subsequent writer has attempted to re-examine the evidence upon which this great thickness for the pre-Cambrian rocks is based.

My study of the slate area agrees with Newton's observations that the rock series has a cleavage which is practically vertical. However, it was ascertained that this parting is in the nature of slaty cleavage rather than true bedding. The fact that there are partings in two directions in certain localities has been noted by both Crosby and Carpenter, but particularly the latter, who interpreted these to mean that the rocks had been subjected to pressure in two directions; and in some places this explanation is the true one.

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* Geology of the Black Hills of Dakota, p. 263.
† Ibid, pp. 61-62.

In the eastern slates is a broad belt of conglomerate which was discovered by Carpenter. A careful study of its exposures shows that the rows of pebbles and bowlders have no regular relation whatever to the slaty cleavage running across them at various angles at different localities. The pebbles and bowlders themselves are, however, elongated parallel to the cleavage (fig. 2). These phenomena were observed many times at points far apart. Also, bedding lamination, cutting the slaty cleavage, was found at many points, and in places the former is directly transverse to the latter. It follows that the breadth of the slates as measured across their outcrop gives no indication of their true thickness. The fact that certain belts of

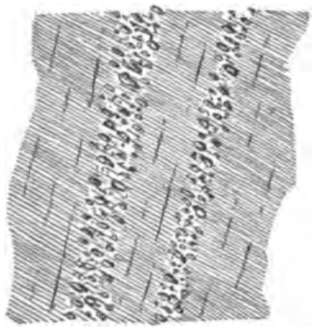

FIGURE 2.—*Bands of Conglomerate cutting Slaty Cleavage.*
The elongation of the pebbles is parallel to the cleavage.

quartzites and schists, having a general resemblance, are found parallel to each other would seem to indicate that such belts are repeated by folding. Within the brief time given to field study no attempt was made to work out the structure of the pre-Cambrian rocks in detail; but clearly the whole question of their real thickness is thrown open. That slaty cleavage was mistaken for bedding by Newton is not strange, for that schistose structure and slaty cleavage not only may be, but very often are, completely independent of bedding was, a dozen years ago, by no means so widely recognized as at present.

Starting with Newton's ideas of the distribution and lithological distinctions between the slates and schists, I began my study, believing that in all probability the schists and granite represent an older formation than the slates. Also, I supposed the two formations were either unconformable, or, if in apparent conformity, were so by subsequent squeezing.

The area about Deadwood, in the northern hills, is entirely within the slate area as mapped by Newton (fig. 1). To my surprise, upon nearing that place, the rocks became more and more crystalline, and for a considerable area about this mining town the rocks are crystalline schists. Passing

to the southward, slates are again found. Rochford is about one-third the way south in the pre-Cambrian core and near the line dividing the two supposed series. From this place excursions were made both east and west, the first of which ought to traverse the slate area and the second the schist area. So far as could be made out, the rocks were not more crystalline west than east. Passing southward from Rochford toward Hill City, the course of travel was such that it crossed and recrossed Newton's boundary between the slate and schist series. While to the south the rocks were found to become more crystalline, no difference in this respect was observed east and west. The slate area was mapped as coming directly in contact with the granite in the southeastern part of the pre-Cambrian area. North of the granites were found, for some distance, as thoroughly crystalline schists as anywhere in the Hills, the rocks becoming less crystalline, however, toward the north. A journey was made around the granitic area, and all the way crystalline schists were found surrounding it. These schists everywhere strike parallel to and dip at a high angle away from the granitic core. To a certain extent these relations were noted by Newton, and his observations are verified by Crosby, although neither reached the above generalization. They are of such interest that Newton's words are quoted.* He says:

"West of Harney the strike of the rocks is from north and south to northwest and southeast, and we find the inclosed granite masses running in the same manner. Southward, on French creek at and above the stockade, the strike of the schists is changed, and with them the inclosed granite ridges run nearly east and west. Southwest of the stockade, in Custer park, the schists and granite run north and south, and this strike is exchanged in the eastern part of the park region for an east and west, which bends around on the east side of Harney, becoming the customary trend toward the north and northwest."

* * * * * * *

"The dip of the schists is usually very high and often vertical, though occasionally by local variation it becomes quite low. In several places a difference of dip was noticed between the schistose rocks on the west and the slates on the northeast side of Harney peak, the former being toward the west and the latter toward the east, but the number of observed points of variation was not sufficient to warrant the statement that this difference is a persistent feature of the relation of the two series of rocks. * * * There is found a change corresponding to the change in strike already noticed on French creek, and the dip becomes slightly southward from the vertical. On the headwaters of Red Cañon creek it is 70° to 80° south; on lower French creek 45° south."

Neither Newton nor Crosby say anything about the relative strike of the slaty and schistose rocks north of the granite, although adjacent to it is drawn the line dividing the two supposed series. Our examination showed here, as elsewhere, that the schists strike parallel to the granite—*i. e.*, in an

*Geology of the Black Hills of Dakota, pp. 73 and 55.

east and west direction. The change in the strike of the schist is not abrupt, as might be supposed from the above, but in turning from one cardinal direction to the next all intermediate positions of it are found. The schists then form a broad concentric shell about the granite area. In going north the schistose structure parallel to the granite becomes less and less prominent. A few miles away from it the rocks are found to have a structure parallel to the granite and also one parallel to the slaty rocks to the north, the two being nearly at right angles to each other. Going still farther away from the granite, the slaty structure becomes more and more prominent, until finally the schistose structure parallel to the granite has wholly disappeared. In this passage the rocks have lithologically changed their character. Adjacent to the granites they are completely crystalline. They become gradually less and less crystalline as this rock becomes more remote, until they merge into the unmistakable fragmental slates to the north, gaining the north and south slaty cleavage in proportion as the schistose structure is lost.*

The significance of the foregoing remarkable structural relations do not seem to have struck either Newton or Crosby. It would seem that it is fatal to the idea that the schistose structure represents bedding. It is, however, at once explained by supposing the granite to be igneous. The parting and crystalline character would then be regarded as due to contact action and dynamic metamorphism. This suggested origin of the granite will be discussed later.

We now have reached some conclusions as to the crystalline schists which differ from Newton's. Instead of being in a definitely defined area in the southwestern part of the pre-Cambrian core, they are in two areas, one about the granites to the south, and the other about the eruptives to the north. Nowhere was found a sharp boundary line between the schists and the slates. The evidence which Newton gave for the existence of two series he states to be mainly lithological; also he says that "The line of separation between them can be only imperfectly indicated. Its trend, so far as could be ascertained, is a little west of north." † The difficulty in the location of this line is a direct sequence of the fact that the slates grade into the schists. Mr. Caswell, who did the microscopic work for Newton, clearly appreciated that in mineral composition these two classes are essentially alike. On this point Newton says: ‡

> "Mr. Caswell's examinations show that the same minerals constitute the typical rocks of both series, only in the schists they are more coarsely crystallized, so that the lithological contrast seems to depend more on the degree or character of their metamorphism than on any difference in chemical constitution."

* It would be of interest to ascertain the relations of the strikes and dips of the schists of the extreme southern part of the pre-Cambrian area both to the smaller masses of granite and to the Harney peak mass.

† Geology of the Black Hills of Dakota, p. 54.

‡ Ibid., p. 62.

The only mineralogical difference mentioned between the two series is the greater abundance of garnet and mica in the schists than in the slates, and the rare occurrence of staurolite in the latter.* It so happens that the best occurrence of coarse garnetiferous and staurolitic mica-schists which I know are north of the main mass of granite—*i. e.*, in the slate area as mapped by Newton. In short, no evidence was found that there are two distinct pre-Cambrian series in the Black Hills.† However, from my brief examination, I would not venture to assert that there are not two or more, for I realize that the true structure of such ancient crystalline and semi-crystalline rocks can only be certainly determined, if at all, by the most detailed study; but it appears to be a safe conclusion that the separation of these rocks into two series upon Newton's basis and with his distribution is not warranted by the facts now at our disposal.

Origin of the Granite.

We now come to a question upon which the various writers on the Black Hills hold different opinions.

Newton maps a considerable area as solid granite. South of this are found upon his map other detached areas of the same rock. It does not appear, however, from his descriptions that he considers these areas wholly of granite, but that it is predominant. This mapping has been criticised by Crosby and Carpenter upon the ground that within these areas is found a quantity of crystalline schists. This is unquestionably true, but the fact remains that about Harney peak is a very considerable area which is practically solid granite, although within two miles from this point are found here and there patches of schist. The relations as I saw them are these: In passing away from the central granitic area the schists appear included by the granite. They become more abundant in receding from the central core, until they are finally predominant. The granite is then contained in the schists in a series of veins or dikes, which often run in parallel directions. For instance, near Custer City fifteen parallel ridges of granite were counted from one point within a short distance. As the granite core becomes more distant the ridges become less and less prominent and of smaller size, and finally disappear. While no such rock is mentioned by Newton as occurring in the slate area north of the granites, ridges of it are found here as elsewhere about the main area.

Newton, in discussing the origin of the granite, states that it often contains irregular fragments of schist—some of small, some of great size. He finds

* Ibid., p. 50.

† The idea that there is but a single series in the pre-Cambrian area has also occurred to Professor Carpenter. Upon asking him if he had ever seen any evidence of discordance between Newton's two series he replied that he had not, and that sometimes he doubted whether there really were two series.

the bounding lines between the schist and granite to be always sharp. His conclusion is that the relations are what they would be if the granite were intrusive, and the schist areas fragments caught in it. This conclusion for a part of the granite was first questioned, so far as I know, by Emmons, who speaks of one of the ridges as being pegmatitic. Carpenter regards all the granite as metamorphic; Crosby considers it all pegmatitic.

It seems to me, however, that neither Crosby's nor Carpenter's theory of the origin of the granite sufficiently explains the facts upon which Newton based his opinion that it is in the main eruptive. Also, it will be noted that all my own observations as to the relations of the granite and schists bear toward an eruptive origin for it. The distribution of the two rocks is exactly what we would expect if a great mass of molten material had been forced up from deep within the earth, thrusting aside the slates, breaking and penetrating them by apophyses. Further, as has been seen, the fact that the schists strike everywhere parallel to the granite core and dip away from it is just what would happen if this were the case. Later, when the lithological character of the schists are considered, it will be seen that they also furnish important corroborative evidence of this conclusion. The granite core, the adjacent great granite masses, and the large granite ridges are in general of much the same character, except that there is a variation in coarseness of grain. The small ridges or veins remote from the central masses become at times more quartzose than the average rock, and in a few cases have to some extent a vein structure. It is quite conceivable, indeed probable, that locally subsequent infiltration has played a relatively important part, or even that some of the veins are wholly pegmatitic; and this is particularly likely to be the case with those which have been most closely examined—*i. e.*, those bearing a small percentage of cassiterite. How a part of the granite may be pegmatitic when its great mass is eruptive is easier to understand than upon the hypothesis that, with no known exceptional causes, immense masses of metamorphic or pegmatitic granite have formed within the slates and schists, and yet everywhere are sharply separated from them.

A second crystalline schist area has been noted in the northern hills. Here it will be remembered are abundantly found comparatively late eruptives—rhyolites, trachytes, etc. The quantity of the dikes of these materials over considerable areas is so great as to compose a large part, at least a third, of the total mass of the rock. Also, contained in these later volcanics, have been found by Newton fragments of granite precisely like that occurring to the south. The presence of crystalline schists in the northern hills associated with these volcanics is suggestive of their origin, when taken in connection with the fact that the schists of the south are associated with rocks presumably eruptive. It may be conceived that these crystalline

schists are due to the metamorphosing effects of the modern volcanics themselves, or to the existence at no great depth of a mass of granite like that at Harney peak, as possibly indicated by the presence of fragments similar to it in the newer intrusives.

Age of the Granite.

The relations of the granite to the schists in the southern hills suggest the possibility that its intrusion attended the present Black Hills uplift. However, Newton, in discussing the age of the granite, showed that this could not be the case. He found at the French creek section (I use his words*) that—

"A continuous sheet of the Potsdam passes from a surface of eroded schists to a surface of granite. There was found no intrusion of the granite along the parting between the Potsdam and the schists, and there was found no metamorphism of the Potsdam at the surface of contact with the granite. In these particulars the relations of the granite are strongly contrasted with those of the trachyte of the Hills. Wherever the trachyte appears beneath the Potsdam the latter is uplifted as though by the insertion of the trachyte between it and the Archean, and its lowest beds are at the same time metamorphosed as though by the heat of the molten intrusion. The fact that the granite did not at this locality affect the form and constitution of the Potsdam strata in a manner similar to the trachyte does not well accord with the idea that it was introduced under similar conditions and during the same geological period."

Also, he discovered feldspathic débris, which apparently came from the granite, in the basal conglomerate of the Potsdam sandstone. Professor Headden mentioned similar phenomena in the vicinity of Hayward, on Battle creek. He kindly undertook to re-examine the locality for me, and from his account the following is taken: At the first exposure below Hayward, Cambrian rocks are found to rest upon schists and "granite lenses or dikes." As to the next exposure below, he says that there can be no question that the Potsdam is unconformable to the schist nor that it rests upon the granite, "for here a large mass of granite is covered for perhaps more than a hundred feet by the conglomerate, and the same is to be seen in several places on a smaller scale." Further, Professor Headden finds in the Potsdam conglomerate above Hayward, besides quartz, mica, and feldspar, rather abundant crystals of tourmaline. Since no crystals of this mineral, except of minute size, have been found anywhere but in the granite, this is additional proof that this rock has furnished detritus for the Cambrian basal conglomerate.

The foregoing evidence is conclusive as to the pre-Cambrian age of the granite. The zone of schists about it was then developed and deeply eroded before the beginning of Paleozoic time.

*Geology of the Black Hills of Dakota, p. 78.

PERMANENCY OF CLASTIC CHARACTERS IN ROCKS.

The late Professor Irving, in the later years of his life, and I, as his assistant, gave a good deal of time to investigating the permanency of the evidence of clastic origin in rocks. It has been found that vitreous quartzites, for instance, which formerly were regarded as metamorphic in the old sense, show their fragmental character in the main as well as the day they were deposited. About one hundred localities, the most of them of pre-Cambrian age, are mentioned in Bulletin No. 8 of the U. S. Geological Survey, in which the induration of quartzites was produced by a process of enlargement of old quartz particles or else the deposition of new quartz between the grains rather than a destruction of the original fragments. This list could at the present time be greatly extended, and would include the larger quantity of the Potsdam and post-Potsdam quartzites west of the Appalachian and east of the Sierras, as well as most of those which have been designated as belonging to the Huronian. So far as our experience has extended, practically all quartzites properly so called, of whatever age, thus reveal their fragmental character, except when they have been subjected to great dynamic action. It has been also found that feldspar, both monoclinic and triclinic, and hornblende* have the same power of renewed growth in fragmental rocks exhibited by quartz grains. These phenomena have been observed both in Keweenawan and Huronian rocks. While locally important, enlargements of this sort do not approach in their wide extension to that of quartz grains.

It has been found that pressure alone, or, in other words, the weight of any ordinary amount of superincumbent rock, has been wholly unable to obliterate in the slighest degree the evidence of fragmental characters in quartzites. For instance, a vitreous quartzite is found at the base of the Penokee series of Wisconsin. Above it is the whole thickness of the Penokee series, some 12,000 feet, and over this the great Keweenawan series, estimated by Irving to be 50,000 feet thick at the Montreal river.† It is possible, and indeed probable, that the great synclinal movement which formed the Lake Superior basin and exposed this vast thickness of rocks began before the end of Keweenawan time. This being the case, these quartzites cannot be asserted to have received the entire pressure of what now appears to be the superincumbent mass of rock, but they must have been buried many thousands of feet below the surface. However, the grains of quartz now betray no evidence whatever of this. The particles are not even arranged with their longer axes in a common direction. A quartzite

* Enlargements of Feldspar Fragments in Certain Keweenawan Sandstones; C. R. Van Hise: U. S. Geol. Survey, Bulletin No. 8, 1884, Part II, pp. 44–47. Enlargements of Hornblende Fragments; C. R. Van Hise: Am. Jour. Sci., 3d Ser., Vol. XXX, 1885, pp. 231–235.

† The Copper-Bearing Rocks of Lake Superior, R. D. Irving, Monograph V, U. S. Geol. Survey, 1883, p. 230.

of the same character is at the base of the Wasatch series. This is a scarcely less notable example, its lower parts resting under 30,000 feet of conformable sediments.* Feldspathic detritus, while also exhibiting great permanence when not subject to powerful dynamic action, is not so refractory as quartz. In the "slate conglomerates" of Logan and Murray on the north shore of Lake Huron—a part of the "original Huronian"—the abundant feldspathic débris ordinarily shows its orignal well-rounded forms. In the Penokee series, just referred to, is a belt of mica-slates and mica-schists. These vary into quartzose phases at various points, which show that they, like the quartzites, are unmistakably of fragmental origin. The feldspar has, however, locally in large measure decomposed into quartz and mica, and in the few places where it has been the predominant or sole mineral the decomposing processes have been sufficient to obliterate the evidence of the original clastic character of the rock.† But, upon the whole, the permanency of fragmental characters in rocks when simply upturned, not folded, however old they may be or however deep they may be buried, is astonishingly great.

But the moment actual movement begins within a rock, evidence of fragmental origin is rapidly destroyed. For instance, the great mass of the Devil's lake quartzites of central Wisconsin exhibits perfectly, under the microscope, its fragmental character, but along certain narrow zones slipping action has taken place; the grains have here been elongated in a common direction, and it is hard to find the original clastic cores if they yet exist. Movement within the mass of the rock has obliterated the evidence of its fragmental origin. Of course this idea of obliteration of clastic characteristics by rock movement is as old as Dana's theory of metamorphism. I wish, however, to emphasize their permanency when movement has not occurred, although the rock may now be completely vitreous, crystalline, of great age, and may have been subjected to enormous pressure.

In the Black Hills dynamic action has extensively occurred. Crystalline schists have been formed from unmistakable fragmental rocks. It is the aim of the following pages to determine to some extent the actual meaning of the general word "metamorphism" as applied to these rocks; in other words, to trace out as far as practicable the mineralogical changes which they have undergone.

Lithological Divisions.

Lithologically the rocks of the hills are granite, ancient modified basic eruptives, later eruptives, slates, quartzites and conglomerates, crystalline mica-schists and mica-gneisses, and ferruginous quartz.

* U. S. Geological Explorations of the Fortieth Parallel, Vol. I, Systematic Geology, by Clarence King, 1878, p. 154.

† Upon the Origin of the Mica-Schists and Black Mica-Slates of the Penokee-Gogebic Iron-Bearing Series; C. R. Van Hise: Am. Jour. Sci., 3d Ser., Vol. XXXI, 1886, pp. 453–459.

Resting unconformably upon the Black Hills slates and schists is the Potsdam sandstone, which is locally a quartzite. The induration of this rock has been found by Crosby to be due to the deposition of interstitial silica. He does not find, however, in general that it has coördinated itself with the original grains. My own sections, upon the contrary, show this to be the case in the quartzites collected by us.

The Conglomerates and Quartzites.—No microscopic study has heretofore been made of the character of the changes which the various minerals have undergone in the quartzites, conglomerates, slates, and schists of the pre-Cambrian area, although Caswell gives their mineralogical composition.* In tracing out the series of changes I begin with those rocks which are nearest to their original condition, the quartzites and conglomerates along Box Elder creek, in the northeastern portion of the pre-Cambrian area.

This conglomerate area has been mentioned by both Carpenter and Crosby. It extends several miles along the creek, and has a very considerable breadth. The conglomeratic bands alternate with those which are non-conglomeratic. The bowlders, oftentimes more than a foot in length, are at times very abundant. They vary from this magnitude to those which are so small as to be lost in the matrix. This conglomerate has been subjected to powerful dynamic action. This is evident from the fact that the pebbles and bowlders are elongated in a common direction, in some cases the longer diameters being three times as great as the other dimensions. These elongated pebbles often, instead of having roundish terminations, end in sharp points. Also, in many cases, the pressure has been so intense as to merge the pebbles into each other. In certain places the process has gone so far as to almost wholly destroy the pebbles, it being only possible to discover them upon a polished surface transverse to the plane of schistosity. Cleaved parallel to the foliation or broken, these conglomerates appear to be but a coarse schist. The pebbles and matrix are practically one. This extreme alteration is most frequent with the finely conglomeratic phases. These betray no evidence of their fragmental origin, and taken by themselves would be regarded as ordinary crystalline schists. Some of them have all the characteristics of a coarse foliated gneiss. The associated conglomerates only indicate that these rocks were originally clastic.

The more purely quartzitic bands do not macroscopically so plainly show the action of the forces to which they have been subject. Crosby and Carpenter both noted the elongation of the pebbles of this conglomerate but they agree in the statement that the grains themselves have not suffered by the deforming action. They explain the present elongated nature of the pebbles by supposing the grains to have slipped over each other. These statements must have been wholly based upon the macro-

* Geology of the Black Hills of Dakota, pp. 471–483.

scopic appearances, for when thin sections are examined, a glance shows that their individual grains have suffered deformation, thus accounting for that exhibited by the pebbles themselves. It is probable that slipping action is also a partial cause.

In the purer quartzites, quartz is almost the sole original constituent. The grains are usually simple; they have not been well assorted, varying from those which are of rather small size to those in which the term "pebble" might be applied. They are now usually quite angular; yet in many of them, but by no means in all, the evidence of their fragmental origin is indicated by a film of inclusions about their cores. The angularity of the grains is in part due to the secondary growths, but also it is in part due to the mechanical action to which they have been subject. They generally lie with their longer axes in a common direction, and in many cases are unnaturally long for ordinary erosion particles. In many of the sections is included quite a quantity of black material, mostly oxide of iron. This not only occurs between the fragmental grains, but is also found between the cores and the enlargements, and, what is more important, in parallel lines within the cores of quartz themselves (fig. 3). These lines are almost univer-

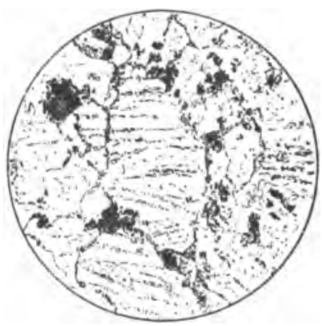

FIGURE 3.—*Thin section of quartz-schist.*

The fragmental grains have been broken perpendicular to their greatest length—*i. e.*, in the lines of pressure—and the cracks as well as the interspaces filled with iron oxide.

sally at considerable angles to the greater dimensions of the grains—that is, divergent from the direction of schistosity; also each grain of quartz, instead of extinguishing simultaneously over its whole area, extinguishes with minute differences of orientation, the maximum variation in a single grain ranging from one to several degrees, and in some cases reaching ten or fifteen degrees. This black material, in the enlargements of the old grains and in the newly crystallized interstitial quartz, is plainly a secondary infiltration product; but the material included in the original grains transverse to their elongation is like this and must be believed to have been introduced at the same time. In some cases large grains have been fractured so as to produce

cracks of such magnitude that not only black ferrite but finely crystalline quartz has been deposited between the parts, thus recementing them. In other cases, instead of ferrite, are found rows of minute inclusions, which are gas or liquid filled, running in parallel lines directly across the section, transverse to the longer axes of the quartz grains (fig. 4). In other cases

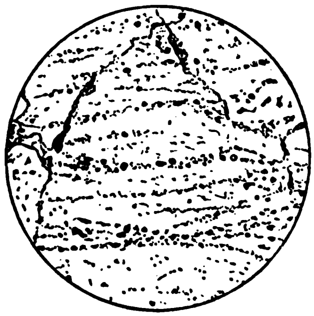

FIGURE 4.—*Part of a thin section of quartz-schist.*
Showing liquid and gas filled cavities of a secondary nature.

the disintegration of the quartz particles has gone farther. An individual, instead of extinguishing upon the whole as a unit, is now composed of individuals which extinguish more or less independently (fig. 5; figs. 1 and 2, plate 4), although the positions of extinction are not far from each other,

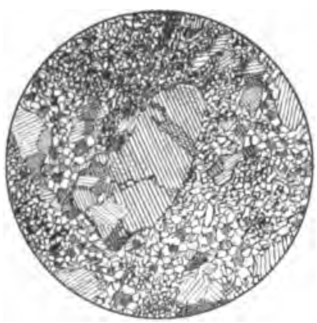

FIGURE 5.—*Thin section of quartz-schist.*
Showing the manner in which a large fragment of quartz is broken down by dynamic action.

except the grain has been wholly destroyed. When the disintegration of the quartz has proceeded thus far, it often happens that two adjacent fragments have merged together in part, so that it is impossible to determine exactly the line of separation between the two. It is not ordinarily the case that all of the grains of quartz are wholly destroyed, nor does it often happen that all of them are practically intact. Every grade of variation from one extreme to the other is sometimes found within a single section, and the more

schistose phases of the quartzites differ from the least schistose phases in the degree to which this process has been carried out.

All the foregoing facts are explained if it be assumed that these rocks have been subject to so great a pressure that movement has occurred within them, elongating all the grains, destroying the perfection of the orientation in the particles, or actually breaking them down altogether. Their elongation transverse to fracture and in the lines of pressure, with the introduction of inclusions along the cracks, are just the phenomena which would be expected from the well-known mechanical experiments on minerals and rocks by Daubrée and O. Lehmann. If there was no macroscopic evidence that these quartzites and conglomerates had been subject to powerful mechanical action, the microscopic evidence would be conclusive upon this point.

The presence of parallel lines of inclusions, both solid and fluid, running continuously across sections is a matter of some interest (figs. 3 and 4). That the rocks showing this are clastic and the inclusions secondary in the Black Hills is indisputable. Mechanical action has cracked the grains in parallel planes. These cracks have become filled with liquid. Later, by the deposition of quartz, they have again become cemented and retain at times numerous liquid inclusions. Cohen,* in his memoir upon the rocks of the Obere Weilerthal, argues that a certain quartz-schist is not of clastic origin. He brings as proof against this the presence of a great number of pores which are liquid filled, arranged in straight lines running from one grain to another. It is evident that this appearance has not the force which he assigns to it. At various times the presence of liquid filled cavities has been taken as indicating the origin of the quartz in which they were contained, some maintaining that such quartz cannot be igneous, but must be of metamorphic origin or formed by aqueo-igneous fusion. It is evident, since such inclusions may be secondary, that this phenomenon cannot be used to explain the origin of a quartz.

The pebbles and bowlders of the conglomerates are usually either simple or complex fragments of white quartz, which could have been derived from veins or from a coarse granitic rock. Some of the quartz pebbles, however, both in hand specimens and under the microscope, appear themselves to be of fragmental origin. This clastic appearance, if not deceptive, would indicate that there were breaks in the deposition of the series and that an earlier formation yielded detritus to a later, or else that before these ancient crystalline slates and quartzites were deposited there existed other fragmental series from which they obtained a portion of their detritus. Crosby and Carpenter speak of the materials of the conglomerates as having been derived from the crystalline schists and granites to the southwest; upon what evidence, how-

* Das Obere Weilerthal und das Zunächst Angrenzende Gebirge: E. Cohen: In Abhandlungen zur Geologischen Specialkarte von Elsass-Lothringen, Band III, 1889, p. 186.

ever, does not appear. In no case have I been able to find a truly granitic pebble in the conglomerates, although the presence of feldspar, both orthoclase and plagioclase, in the quartzites and conglomerates indicates that they have probably been derived from some such rock as gneiss or granite. The identification of the source of detritus is in general a very difficult thing to do, and that in this case the material was from the particular granite and schists now exposed in the Black Hills seems to have been assumed without proof.

The feldspar of the quartzites and conglomerates has usually decomposed to such an extent as to have lost its original rounded character. The resultant products are muscovite, biotite, and less frequently kaolin, accompanied by a simultaneous separation of quartz. Generally the decomposition has taken place to the greatest extent upon the exterior of the grains, but affects them, more or less, quite to their interiors. In some sections all stages of the change are seen, from that in which the mica forms a circle of folia about and penetrating a feldspathic grain to that in which nothing remains of it.

The interstitial material in the quartzites and conglomerates is chiefly finely crystalline quartz which has been deposited as independent particles. The induration of the rocks is then due both to the enlargement of the old grains and to the deposition of new quartz. Pressure also may have had its influence. The total amount of infiltrated silica is very considerable, although the fragmental grains are of various sizes, fit closely, and consequently leave an unusually small amount of interstitial space. This amount of deposited quartz is increased by numerous quartz veins.

The fact that iron oxide has oftentimes been a subordinate filling material makes it frequently easy to determine just what part of the quartz is an original detrital material and what a secondary deposition, the former excluding and the latter including the ferrite. Accompanying the interstitial quartz and iron oxide is a greater or less quantity of muscovite or sericite, or both. The quantity becomes so great in certain cases that the rocks could well be called a muscovitic or sericitic quartzite, while it occasionally passes over into a muscovite-slate, or sericite-slate, or schist of the same kind. Other minerals, such as iron and other carbonates, and tourmaline, are present as infrequent additional accessories.

The micaceous slates associated with the quartzites and conglomerates differ from them only in that the amount of feldspar in the original detritus has been greater and the particles of smaller size. The decomposition of this mineral has produced both biotite and muscovite abundantly and the rock has passed over into a slate. The nature of this process will appear later in more detail.

The quartzites and conglomerates above described differ profoundly from

the Cambrian quartzite mentioned and other quartzites in which the outlines of the original grains have not been modified since deposition. This difference is plainly due to the powerful dynamic action to which they have been subject. In their transformation no evidence has been discovered to show whether any of the material has ever been highly heated, as is usually assumed to be the case in metamorphosed rocks. Siliceous induration is known frequently to occur as a surface phenomenon. So far as can be seen, the causes which have obliterated to a greater or less degree the evidence of clastic characters are purely chemical and mechanical. It is easy to see that, in the non-conglomeratic phases of rock, if the squeezing had been somewhat more intense, the proof of fragmental origin in them would have been wholly obliterated. It is to be noted in this connection that the coarse conglomerates which have an unusually crystalline matrix show, macroscopically, most strongly the deformation effects and merging together of the pebbles.

The silica-bearing solutions which traversed the Black Hills quartzites and conglomerates were not only capable of depositing, but, as shown, did actually deposit quartz, thus preventing these rocks from becoming pulverized during the movements through which they passed. When cracks formed of sufficient size, either in the rock as a whole or in the individual grains, they were at that time or subsequently cemented with new quartz. At favorable moments the particles began growing, each coördinating the new quartz to itself. Also in the interspaces independent quartz was deposited. Consequently, while the most schistose of these rocks have now become composed of angular interlocking particles of quartz, showing little or no evidence of clastic character, they are not less strong than vitreous quartzites which have become completely indurated without motion by the growths of the old rounded grains until the enlargements met and interlocked.

The solution of silica in rocks—given the element of time—with great readiness, and its deposition as quartz in the interspaces of rocks in vast quantities, seem at first almost incredible; yet no one who has examined microscopically the quartzites of our continent can doubt for a moment that such is the fact. For the most part in ordinary quartzites the original grains lie as round and perfect as the day in which they were deposited in sandstones. Suppose a sandstone to be composed of spherical grains of quartz of equal size, the particles being packed as closely as is geometrically possible, the amount of new quartz required to completely fill the interspaces would be twenty six one-hundredths (R. S. Woodward) of the total space, or more than one-third of that occupied by the original grains. As a matter of fact, under natural conditions this amount has never been deposited, because the grains of sandstones are not spherical nor of equal size; because the inter-

spaces to some small degree are filled with other materials; and because it cannot be asserted that they are ever perfectly filled, although apparently this is often the case. This very large theoretical amount of silica is approximated in the somewhat rare, evenly granular, pure, vitreous quartzites. It is certain that the amount of secondary quartz required to indurate such vast formations as the Paleozoic and pre-Paleozoic quartzites of the west is enormous.

The thicknesses of the Weber, Ogden, and Cambrian quartzites of the Wasatch, using Emmons' and King's lowest estimates, aggregate 18,000 feet.* The Uinta sandstone and quartzites have an estimated thickness of from 10,000 to 13,000 feet.† The quartzite of the Medicine Bow mountains of Wyoming is of great, although undetermined, thickness.‡ The combined area covered by these quartzites is thousands of square miles. An examination of my collection of specimens and thin sections from all of these regions shows that the chief cause of the induration of the rocks is interstitial quartz, the major part of which has been added to the original clastic grains. The quartz deposited in vein filling is as nothing compared with this.

As to the source of these vast quantities of silica, we can at present do little more than conjecture. It seems to be taken for granted by most writers that quartz itself is wholly insoluble within the crust of the earth; that in order to be dissolved the silica must be in the colloid form. These are points upon which evidence is needed. That much silica is derived from and taken in solution during the decomposition of silicates cannot be doubted. We know that silica is often largely contained in the water of hot springs.§ Is it not probable that the water deep within the crust, therefore presumably at a relatively high temperature, carries ordinarily a considerable quantity of silica which is ready to be deposited when favorable conditions arise? Numerous experiments upon crystallization show that the presence of crystallized nuclei in a solution is very favorable for the deposition upon them of like material. In the quartzites we have such nuclei in the rounded grains of sand.

In the elder Hitchcock's remarkably able studies upon the metamorphism of rocks,|| published in 1861, are described some extensive conglomerates associated with and passing into crystalline schists, which are very similar to those of the Black Hills. He had not the microscope to assist him; yet

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*United States Geological Explorations of the Fortieth Parallel, Vol. I, Systematic Geology, by Clarence King, 1878, pp. 155-156.

† Ibid., p. 150; Geology of the Uinta mountains, J. W. Powell, 1876, pp. 143-144.

‡ United States Geological Explorations of the Fortieth Parallel, Vol. II, Descriptive Geology, by Arnold Hague and S. F. Emmons, 1877, pp. 104-109.

§ For foreign localities, see Roth's Allegemeine und Chemische Geologie, Vol. I, 1879. For United States localities, see Bulletins of the U. S. Geological Survey, No. 32, Lists and Analyses of the Mineral Springs of the United States, Albert C. Peale, and No. 47, Analyses of Waters of the Yellowstone National Park, with an Account of the Methods of Analysis employed, Frank Austin Gooch and James Edward Whitfield. The latter bulletin gives over forty water analyses, in all of which silica is found. In many it constitutes twenty-five or more per cent. of the total soluble material, while in one case it runs as high as fifty per cent.

|| Geology of Vermont, Edward Hitchcock, Vol. I, pp. 22-52.

his field studies prove conclusively, as it seems to me, that genuine crystalline schists have developed from clastic rocks at Newport, Rhode Island, and East Wallingford and Plymouth, Vermont. Not only is this true, but in general his conceptions as to the manner in which the change occurred show great insight. Many of his figures are almost identical in ideas with the figures published of the well-known schistose conglomerates of Norway and Germany, more recently described.

The pebbles of the Vermont conglomerates are mainly of quartz. Hitchcock could not believe, as was maintained by Tyndall,* that so rigid a substance as quartz, however great the pressure to which it was subject, could suffer internal movement and retain its strength. That silica is so readily and extensively transferred in rocks he had no means of knowing; hence he was driven to explain the presence of the distorted quartz pebbles by supposing that they represented residual silica from silicates. We now see that both Hitchcock and Tyndall were in part right and in part wrong. The process of elongation of quartz is analogous to but not like the flow of ice in a glacier. The distortion is chiefly accomplished by fractures and regelations, the quartz remaining rigid and solutions being present to serve as a carrier of silica; whereas the substance of a glacier itself is alternately liquid and solid. It will be noted that for this metamorphism a high degree of heat is not requisite, as is commonly assumed. The temperature of hot springs is certainly sufficient, but it is not asserted that a higher temperature was not actually present, although it is manifest that no such heat and pressure obtained as would be requisite to render quartz itself in any degree plastic. The possibilities as to the plasticity of many rocks, under ordinary conditions as to heat, when brittle quartz is found to be capable to a certain extent of flowage, are very suggestive.

Another line of study presents itself in considering these squeezed conglomerates. It may be assumed in general that the matrix has been elongated as much as the pebbles. By taking many measurements of normal erosion pebbles and thus getting the ratio between their longer and shorter diameters, and doing like work with the pebbles of the same composition and magnitude in conglomerates which have been subject to dynamic action, we would be able to get an approximately reliable quantitative measure of the amount that the beds have been diminished in thickness by the mechanical action to which they have been subject. This has not been done with the Black Hills rocks, but it is safe to say the diminution in thickness of the original beds is very considerable.

The Mica-slates and Mica-schists.—The slates, quartzites and conglomerates occur in a broad belt in the center of the pre-Cambrian area, the conglomerates being more largely known to the east. Passing north or south from this

* Glaciers of the Alps, John Tyndall, 1861, pp. 404–407.

belt, the rocks become more crystalline and grade into the schists about the volcanics to the north and the granite of Harney peak to the south. In the field no unmistakable fragments have been found by me in the schists immediately adjacent either to the granite or the volcanics, although certain obscure forms were seen which may represent what may have been fragments. In the transition in both directions, greywacke-slates change to mica-slates; the mica-slates to non-foliated mica-schists; the non-foliated mica-schists into foliated mica-schists (which are both garnetiferous and staurolitic), and even into gneisses. This gradation is not made out in any one continuous exposure, but by many sections of detached exposures, in all of which the same phenomena are observed.

The steps in the process of transformation, as seen under the microscope, are in many respects like those I have already described as occurring in the upper slates of the Penokee series.* Later, Bonney † described some mica-slates which have a similar origin. In the Black Hills, however, the resulting crystalline schists are coarser grained and more foliated than any of these rocks. Also, unlike those of the Penokee area, they have been subjected to powerful dynamic action, and this has had an important influence in their development. The processes, in brief, which have changed these once detrital quartz-feldspar rocks to thoroughly crystalline mica-schists are, *first*, the alteration of the feldspar to the minerals muscovite, biotite and quartz; and, *second*, the breaking down of the larger clastic quartz individuals by mechanical action. The first of these processes I have already described in detail in the paper alluded to. By it crystalline schists are produced from feldspar detritus. These details I need not repeat; but the decomposition of fragmental feldspar is most beautifully shown in the Black Hills rocks. It will suffice to say that as a result of this process an intricately interlocking mass of crystalline quartz, feldspar and mica, or quartz and mica, are produced from each of the large grains of clastic feldspar (figs. 1 and 2, plate 4). Usually many independent individuals of quartz and mica occupy the space once taken by a single individual of feldspar. The reticulating residual feldspar for a given fragmental grain acts as a unit, except the process of recrystallization results in the formation of feldspar of a different kind from the allothigenic individual. When the process is complete, the interlocking mass consists wholly of quartz and mica. This alteration is chemically possible because the micas, both biotite and muscovite, are much more basic than feldspar and the residual silica separates as quartz. By imperceptible steps all phases of the alteration are seen, from

* Upon the Origin of the Mica-Schists and Black Mica-Slates of the Penokee-Gogebic Iron-Bearing Series, C. R. Van Hise: Am. Jour. Sci., 3d ser., Vol. XXXI, 1886, pp. 453–459.

† On some Results of Pressure and of the Intrusion of Granite in Stratified Paleozoic Rocks near Morlaix, in Brittany; On the Obermittweida Conglomerate, its Composition and Alteration; Notes on a Part of the Huronian Series in the Neighborhood of Sudbury (Canada), by T. G. Bonney: Quart. Jour. Geol. Soc., London, Vol. XLIV, 1888, Part I, pp. 11–19, 25–31, 32–44.

those in which the feldspars are practically unchanged or surrounded by a mere film of biotite and muscovite to those in which, in place of a large grain of feldspar, is found a thoroughly interlocking mass of muscovite, biotite, and quartz.

One rock presents a modification of this process which is worthy of note. Macroscopically it contains a good many roundish or oval fragments of black, aphanitic, cherty-looking material, some of them one-fourth of an inch or more in diameter. Under the microscope these turn out to be feldspars which have been cracked and impregnated through and through with the ferrite found so plentifully in many of the rocks. Their true nature is discoverable only in those cases in which the amount of this material is smaller than usual. Gradations are found from grains of which the character is evident to those almost opaque from included ferrite.

The original quartz grains have generally been elongated in a direction parallel to the schistose structure, as in the conglomerates and quartzites before described. In many cases it is not possible at the present time to tell what part of the quartz is original and what secondary; but frequently, simultaneously with the other changes, has been deposited abundant ferrite, just as in the quartzites and conglomerates. When this has occurred it marks off with perfect clearness the original fragmental quartz from the secondary minerals. When the schists have become more thoroughly crystalline the only minerals now present which were originally deposited as such are the cores of quartz in the larger elongated particles. In certain cases the fragmental character of the quartz grains is not shown by such inclusions but by minute flakes of white mica, which are included in the enlargements and lie in curved lines about the cores. These are not so continuous as the ferrite inclusions, but are sufficiently so to form well defined ovals. Unlike the former, these folia are only discovered in polarized light.

Often the fragmental quartz which has been mingled with the feldspar has been rather fine-grained. In these cases it is not at a glance distinguishable from newly developed quartz. In other cases the quartz particles have been large; and here, unless the pressure has been very great, they stand out with rounded outlines in a thoroughly crystalline matrix (figs. 1 and 2, plate 4). However, in the most crystalline phases of the schists immediately adjacent to the granite, the pressure has been so great that even when the fragmental quartz was coarse the rock has now an evenly granular, roughly banded arrangement of mica and quartz. These rocks are as coarsely and completely crystalline as mica-schists which occur in the indisputably fundamental gneiss. The quartz and mica are concentrated more or less in alternate bands and irregular areas just as in such rocks. The mica folia average about 1^{mm} in greatest length, and the quartz particles, of quite uniform size, are one-half to one-fourth as long. The only

thing which now shows the original position of the clastic particles of quartz and feldspar is the relative distribution of the minerals. The areas in which quartz is almost the sole constituent probably represent quartzose fragments which have been broken down by dynamic action, while the areas which are largely micaceous probably represent places once occupied by feldspar.

As we pass from the less crystalline to the more crystalline mica-schists there is a gradual increase in the size of the secondary quartz particles. This is just what would be expected from their manner of development. The more plainly fragmental the rocks are, the finer crystalline is the background. Naturally when the recrystallizing forces have become greater the particles which are authigenic grow to a greater size, and this process being accompanied by powerful dynamic action the large fragmental quartzes are at the same time broken into small particles (fig. 2, plate 4). It follows that it is entirely possible to produce from a coarse-grained quartz-feldspar detritus a crystalline schist in which the quartzose background is composed of grains of approximately uniform size, and which contains mica in large flakes, scattered here and there in bands or irregular areas. That this statement represents the actual facts in certain schists of the Black Hills, except that the broken down quartz is a little coarser than the authigenic, cannot be doubted by any one, I think, who will observe the gradual transitions in the field and see the corresponding mineralogical changes in thin section.

In the mica-schists the two micas, muscovite and biotite, are both abundant, although biotite is upon the whole rather more plentiful. Occasionally muscovite is predominant. Frequently also chlorite in well defined leaflets is present as a subordinate mineral. These minerals are for the most part secondary developments. If any original mica is now present, it is in subordinate quantity. The micas are arranged to a remarkable degree with their longer axes in a common direction parallel to the schistose structure (fig. 2, plate 5). Sometimes, as will be seen, where there is a slaty cleavage or schistose structure in two directions, the mica flakes show a peculiar double arrangement corresponding to them (fig. 1, plate 5). The general perfection of the linear parallel arrangement of the micas and the quartz, the beauty of the former minerals, and the absence of all others as important constituents combine to make these rocks the most perfect examples of mica-schists that I have seen.

The greywackes, mica slates and mica-schists frequently become very fine-grained and pass into aphanitic slates and schists. These, however, need no detailed description, as they repeat with smaller particles the same story told by the coarser-grained rocks. In certain of them, evidence of fragmental origin is found; in others it is wanting. These rocks appear to have differed chiefly from the mica-slates and mica-schists in that the original detritus was much more finely comminuted and doubtless contained a rela-

tively larger proportion of purely clayey materials. They also contain in many cases a very large proportion of pyrite mingled with the ferrite. The total of these ferriferous materials is much greater than in any of the coarser-grained micaceous rocks. Newton states that the black slates contain carbonaceous material. If this is the case, and I have no doubt that it is, the presence of the large amount of iron sulphide may be explained by the reducing action of such organic matter.

In a few cases have been found, in the less thoroughly crystalline greywackes. a class of rock in which the alteration product of the detrital feldspar is a variety of amphibole. In this decomposition the relations between the feldspar and amphibole are exactly like those between the feldspar and mica above described. The amphibolitic greywackes differ macroscopically from the micaceous greywackes only in that they are greenish-grey rather than grey. These rocks suggest the possibility that the decomposition of a quartz-feldspar fragmental rock may also under favorable circumstances produce a hornblende-schist; but while hornblende-schists are found intimately associated with the micaceous slates and schists, the connection between them and these greywackes, if any exists, has not been worked out.

The Mica-gneisses.—In most of the mica-schists the conditions have been such that the old fragmental feldspars have decomposed. In a few of them are found small individuals of perfectly fresh feldspar which inclose particles of secondary ferrite. From their appearance they are taken, like the mica, to be a new crystallization. As was first described by Teall,* and subsequently by other writers, old feldspars have here broken down, and at the same time new ones have formed of a different character. In a few cases among the most crystalline of these mica-schists the amount of such original feldspar is sufficient to make the rocks a muscovite-biotite-gneiss. In their macroscopic appearance these rocks do not differ from the mica-schists just described. In thin sections, their background, instead of consisting almost wholly of quartz, as in the mica-schists, is of evenly granular quartz and feldspar in approximately equal amounts. The feldspars are for the most part perfectly fresh, and comprise orthoclase, microcline, and plagioclase. The latter is twinned both according to the albite and pericline laws, both kinds of twinning often being found in the same individual. The interlocking of this quartz-feldspar background is as intricate as in any ordinary crystalline schist of the same degree of coarseness. Both micas are abundantly present, biotite being the more plentiful. The blades are arranged in a common direction to a considerable extent. In one case the twin lamellæ of the plagioclase generally correspond in direction to the folia of mica and the elongation of the grains of quartz. In the cases of microcline and the double twinned plagioclase the twin lamellæ of course run in this

* The Metamorphosis of Dolerite into Hornblende-Schist, J. J. H. Teall: Quart. Jour. Geol. Soc. London, Vol. XLI, 1885, p. 139.

direction and also at right angles to it. Contained abundantly are very numerous particles of iron oxide—hematite,—many of which have crystal outlines. If it were not that this inclusion chances to be present there would be nothing in the thin sections, so far as one can see, to show the genesis of these rocks. When they are examined closely it is seen that while this material is contained in the most of the feldspars, in the mica and in the smaller particles of quartz, it is only contained in the exterior portions of the larger particles of the latter mineral. These show round or oval cores which are perfectly free from this inclusion. In these rocks, as in the thoroughly crystalline mica-schists, the cores of quartz stand as the only representatives of the original detritus. All other materials have recrystallized. That the major part of the feldspar is really authigenic rather than remnants of clastic particles is shown by its freshness, by its inclusions, and by the fact that in one case its twin lamellæ, probably in obedience to pressure, uniformly follow the direction of schistosity.

Garnet, Staurolite, and Tourmaline.—In all the foregoing rocks are found various accessory minerals, the chief of which are garnet, tourmaline, and staurolite, although Newton says tourmaline occurs only in the granite.* Within the quartzites, conglomerates, and greywackes these minerals are relatively unimportant. They increase in abundance as the rocks become more crystalline, and in some cases they become principal constituents. Garnet is much more widespread than the other two, although the amount of tourmaline and staurolite present is very considerable. These minerals all have the characteristics usual when occurring in crystalline schists, and they will therefore not be described in detail. As much has not been made out as to their manner of growth as could be wished. There is little doubt that they, like the mica and interstitial quartz, are secondary constituents.

The garnets usually do not reach a magnitude of more than 2^{mm} in diameter, while their average is much smaller than this. In their growth they have shown remarkable power in excluding or absorbing other minerals. Biotite is generally not included at all in the garnets of the coarser, although quite often included in those of the finer grained schists and slates. Quartz is included to a greater or less extent, and in some cases quite largely. The frequent absence in the garnets of the black ferriferous material which is plentiful in the remainder of the section suggests that as the garnet has grown it has absorbed much of that material. In the cases in which the amount of ferrite or pyrite is very great the garnet has not been able to wholly exclude or absorb them. In many cases the inclusions within the garnets are more abundant near their centers than in their exterior portions. This may mean that during the first part of their growth only was the ferrite being abundantly deposited. Often also the inclusions are arranged in

*Geology of the Black Hills of Dakota, p. 70.

parallel lines. In some cases these lines are parallel to the schistose structure; in others they are at an angle of about 60° to that structure, as though the time of the growth of the mica marked a different epoch from that of the garnet. Often the black material is arranged in such a fashion as to show to some extent the manner of the growth of the garnets—that is, included particles are arranged in lines which radiate from the centers. Further, a garnet area is often subdivided by strongly marked lines of inclusions, so that it has the appearance of consisting of several individuals which have a cleavage which in each part is approximately parallel. This apparent cleavage is of course not that, but is due to rows of inclusions.

The staurolite, as is characteristic with this mineral, includes alike all the other constituents with which it comes in contact, sometimes the area which a crystal occupies being fully one-half taken by extraneous minerals.

The tourmaline, even to a greater extent than the garnet, has shown power to wholly exclude all other minerals. One tourmaline mica-schist is worthy of a detailed description. This rock is a black, evenly laminated one, showing large folia of mica and lustrous crystals of tourmaline; is strongly foliated so that its cleavage surface gives back a brilliant sheen. It is finely laminated, the laminæ being of slightly varying color. Altogether the rock has the appearance of a completely crystalline hornblende-gneiss. As examined in thin section the background appears to consist almost wholly of quartz, although there may be more feldspar present than would be thought. There is no decisive evidence that any of this quartz is fragmental, but occasional grains have vague lines of inclusion in their outer parts which may indicate that clastic cores are present. Scattered through this background in about equal quantity are tourmaline and mica, the latter including both muscovite and biotite. The tourmaline is almost wholly in well defined crystals. The section is cut parallel to the schistose plane of the rock—*i. e.*, parallel to the greater number of laminæ of mica,—so that most flakes are basal. The tourmaline, on the other hand, is as uniformly cut parallel to the vertical axis. There is also a tendency for the majority of the vertical axes to arrange themselves in a common direction in the plane of schistosity, but this fails to carry with it many individuals. If pressure has been the controlling force in the initial arrangement of the particles of mica and tourmaline, these relations—*i. e.*, the biotite basal and the tourmaline longitudinal—are just what would be expected. The tourmaline is abundantly included in all the other minerals. The biotite frequently contains black particles of ferrite, which suggests that possibly this accessory has been the factor which controlled the location of the folia of biotite.

Immediately adjacent to the large granite masses in the southern part of the hills are found certain very coarse muscovite-biotite-gneisses which contain much feldspar. These, upon the whole, are more analogous to the granites

than to the mica-schists and mica-gneisses above described. Their genesis is uncertain. They may be merely foliated phases of the granite, or they may be masses of the clastic rocks which were caught within the granite and so profoundly altered as to lose all trace of their fragmental character.*

Other Crystalline Rocks.—I shall not attempt in this paper to give a detailed description of the several other kinds of rock which occur in the pre-Cambrian core of the Black Hills. In order to make a comprehensive comparison with other localities, it is, however, necessary to briefly characterize them.

The first in importance among these are the quartz-rocks, ferruginous cherts and schists. The chief constituent of this class is finely but completely crystalline interlocking quartz in particles of quite uniform size. No evidence is observed that any of them are fragmental. The chief remaining substance is iron oxide, which occurs in the forms of limonite, hematite, and magnetite. The only other constituent of importance is muscovite. Occasionally a little biotite and iron carbonate are seen. The iron oxide is often concentrated into layers, and thus locally makes up a considerable proportion of the rock. The highly ferriferous layers are interlaminated with those that contain much less iron oxide. These oxides usually have crystal outlines, and the particles are arranged in entire independence of the quartz. The relations of the two minerals are just what they would be if the iron oxide had wholly crystallized before the silica appeared. The quartzose phases are called " quartz-rock " in order to separate them from the quartzites, the latter term being restricted to rocks which are chiefly composed of worn fragments of quartz. This distinction has proved to be a fundamental one in the Lake Superior region, in which the cherts and jaspers of the iron formation are always non-fragmental, while the quartzites are as plainly clastic. This class of rock, as observed by Newton, is then remarkably like in mineral character to the ferruginous schists of Lake Superior, the chief difference being that muscovite in one phase of the Black Hills rock is substituted for actinolite in the corresponding rock of Lake Superior. This microscopic likeness is no stronger than the macroscopic resemblance.

The fact that associated with the mica-slates and mica-schists are ridges and large masses of coarsely crystalline, dark gray or green, massive to schistose rocks which resemble altered greenstones has already been mentioned.

* In connection with the foregoing upon the development of the mica slates and schists, the remarkable studies of Sorby, began many years ago, should be mentioned. As early as 1863 his microscopic studies showed that certain mica-slates are of fragmental origin. Many years later (1880) he again took up the subject and presented additional evidence, not only that this is true, but that the mica and much of the quartz in certain rather crystalline mica-schists and slates are secondary developments. He was not able, however, with the material at his hand to work out the manner of the genesis of these minerals, nor does their source seem to have occurred to him except in a general way as developing from the original mud. His work in connection with this study as to "stratification foliation" and "cleavage foliation" is too well known to need reference. See "On the Original Nature and Subsequent Alteration of Mica-Schist," H. C. Sorby, Quart. Jour. Geol. Soc., Vol. XIX, 1863, pp. 401–406; "On the Structure and Origin of Non-Calcareous Stratified Rocks," H. C. Sorby (part of Anniversary Address of the President of the Geological Society of London), Quart. Jour. Geol. Soc., Vol. XXXVI, 1880, Proceedings, pp. 46–92.

Upon examining their sections, it turns out that they vary in character from a somewhat altered unmistakable diorite to a completely crystalline hornblende-schist or chlorite-schist. While sufficient time was not given to a study of their field relations, no evidence was seen that any of them vary into the mica-slates and mica-schists. They are all regarded as ancient eruptive rocks which have partaken of the alteration-effects of the forces that metamorphosed the fragmental series. This being the case, we have within the Black Hills pre-Cambrian area, schists which are of eruptive and of clastic origin. In only one or two cases has a hornblende-schist been found, however, which shows any indication of belonging to the clastic series, and in this rock a larger amount of biotite than hornblende is present. The foregoing rocks, with the exception of that just alluded to, are very similar to certain rocks of the Lake Superior region in which Dr. George H. Williams has carefully traced out series running from undoubted eruptives to hornblende-schists and chlorite-schists.* My lack of material, as well as limitation in space, prevents an attempt to do the like with the Black Hills rocks. However, it may be said that the thin sections give a tolerably complete gradation from an unmistakable diorite to one in which the e is little or no feldspar, quartz and hornblende taking its place, and the rock becoming a crystalline hornblende-schist. A further set of alterations has then seized upon certain of them so that their background contains, in addition to the quartz, a good deal of calcite. At the same time the hornblende has passed over into chlorite or into chlorite and epidote, the rock thus becoming a chlorite-schist or an epidotic chlorite-schist.

The granites have been so fully described by Newton and Caswell that I need give them little space. They are in the main coarse-grained muscovite-granites, the only important minerals being muscovite, quartz, and feldspar, the latter including orthoclase, microcline, and plagioclase. These granites are sometimes so coarse as to give muscovite approaching that of a merchantable character. These coarse phases are by no means universal; and they pass into rocks which have all the characteristics of muscovite-biotite-granites of the ordinary type. Also, quite frequently they vary into tourmaline-granite, this mineral being occasionally the only important one aside from the quartz and feldspar.

Nature of Original Sediment.

The foregoing study shows that the detritus from which the Black Hills schists and slates have developed was almost wholly quartz and feldspar—perhaps mingled in places with so fine a material that it could only be called mud. Most original rocks from which quartz and feldspar are largely

* The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan, by G. H Williams: Bull. U. S. Geol. Survey, No. 62 (in press).

derived also yield mica abundantly. In the slates and schists of the Black Hills these three minerals occur together, but it has been seen that much, if not all, of the mica is authigenic. The specific gravity of quartz and feldspar differ but little, and it requires very favorable natural conditions to perfectly separate these minerals. That these peculiar conditions not infrequently maintain for a time is shown by the interlaminations of pure quartzose sediments and those composed of quartz and feldspar, which is found in many localities. Mica, while having a higher specific gravity than quartz or feldspar, usually floats longer than particles of the same weight of these minerals, because of its ready separation into thin flakes, and may thus be carried to more quiescent deeper water. The conditions of sedimentation in the Black Hills have ordinarily been such that the mica has been separated from the quartz and feldspar, while in certain layers represented by the quartzites the quartz has been practically freed from other minerals. It often happens in other localities that, mingled with quartz-feldspar detritus, is a good deal of clastic mica. The original character of the ferruginous quartz-rocks will not be discussed. They are regarded as chemical or organic sediments, or both combined.

Bearing of Microscopical Study upon the Origin of the Granite.

Recurring to the question of the origin of the granite, it would seem that the foregoing microscopic study of the crystalline schists affords additional indication that it is in the main eruptive. It will be remembered that within the central granite mass are contained areas of the schists which appear as though they had been caught in an eruptive rock; that the schists form a zone about the granite, striking parallel with and dipping away from the main mass; and that radiating from the Harney peak core are numerous dike-like ridges which become less frequent and smaller in size as it is receded from. The lithological study shows that the schists become coarser, more foliated, and much more crystalline adjacent to the granite, and also that here are abundant garnet, staurolite, and tourmaline, minerals which are very often produced by the contact of an eruptive with a sedimentary rock. Upon the hypothesis that the granite is eruptive and the cause of the present structure of the surrounding crystalline schists, not only the distribution of the latter is explained, but the peculiar relations of the slates and schists themselves. The strike of the slates is in general in a north and south direction. The schistose structure parallel to and north of the granite is transverse to this; but it has been seen that the slates grade into the schists. Beginning with the slate area and passing toward the granite area to the south, the slaty cleavage in a north and south direction becomes less and less prominent. After a time a schistose structure is found cutting across the slaty

cleavage in a direction at right angles to it. As the granite is approached, the slaty cleavage becomes fainter, the schistosity becoming gradually more distinct, and near the granite the cleavage is wholly replaced by the schistose structure. The change of the original slaty cleavage to a schistose structure east and west of the granitic area did not result in a variation of the direction of foliation, as the new force was parallel to the old: but south of the granite, as on the north, the new foliation is at right angles to the older slaty cleavage.

Corresponding to the double cleavage of the rocks north of the granite is a peculiar arrangement of the mica-folia as seen in thin section. In general, in the slates and schists, the micas are arranged with their basal cleavage parallel to the slaty parting or schistose structure. It is to be expected when the first of these structures yet remains and the second also has developed in a new direction, that a double arrangement of the mica would be found; and such is the case. This phenomenon is best shown in those rocks in which the two structures are about equally prominent and at right angles to each other. Here the larger mica flakes are parallel to the slaty cleavage, while the smaller and more numerous ones are parallel to the schistose structure (fig. 1, plate 5). This curious arrangement corresponds with the genesis of the minerals as worked out. The slaty cleavage is earlier than the schistose structure, and folia of mica had developed with bases parallel to the former before the latter appeared. At the granitic eruption the new mica flakes arranged themselves in correspondence with the developing schistosity. It appears as if this later force at a distance from the granite was not sufficient to rotate the mica particles which had already formed. They continued to grow, and reached a greater magnitude than the newer folia parallel to the schistose structure. In the most crystalline schists adjacent to the granite the new force was able to wholly obliterate all the effects of the previous slaty cleavage.

Bedding, Cleavage and Foliation.

The foregoing studies of the quartz-schists, mica-schists and mica-gneisses suggest some observations on the production of slaty cleavage and foliation. As is well known, these structures develop as a consequence of dynamic action. This results in the arrangement of the original and secondary particles with their two greater dimensions perpendicular to the lines of primary force, producing cleavage or foliation in the plane of these dimensions. Often, also, there is a linear-parallel arrangement of the particles in this plane corresponding to the direction of a secondary force. The work is accomplished by the development of new minerals, which arrange themselves perforce with their longer axes in the directions of least resistance; and, so far as the original particles are concerned, either by their rotation in the flowage of

the rock, or else by their actual deformation, which latter often occasions fracture. The fracture of particles occurs transverse, or at a large angle to, the elongation; for the very yielding of a grain perpendicular to the pressure, if carried far enough, ruptures it at various places transverse to the direction of elongation; i. e., approximately in the lines of pressure. All of these points are beautifully illustrated by the phenomena which have been described in the development of the Black Hills quartz-schists and mica-schists from quartzose and feldspathic sandstones.

The Black Hills thus furnishes one of the best instances which have come to my notice of the independence of slaty cleavage and schistose structure or foliation from true bedding. A great part of the Black Hills pre-Cambrian rocks are of clastic origin; yet the present prominent structures have no definite relation whatever to the original sedimentation. Not only is this the case, but a secondary, well-developed slaty cleavage, which locally passes into genuine schistose structure, produced at the expense of original lamination by powerful dynamic action, has for considerable areas been itself wholly obliterated by a later force, and a new and more prominent foliation produced which cuts across the secondary slaty cleavage at various angles up to perpendicularity. In rare cases a single hand specimen displays what is taken to be the original sedimentation and both of the subsequent foliations cutting each other nearly at right angles. Farther, associated with these slaty and schistose rocks are basic eruptives which now have induced structures parallel to the secondary or tertiary structures of the adjacent clastics, produced at the same time and by the same causes that the like structures were formed in them. The principle that slaty cleavage and schistose structure have very often no connection with original sedimentation is so old a truth that its repetition here seems unnecessary; yet I suspect that geologists sometimes forget this important fact, which should be constantly borne in mind when dealing with metamorphic rocks.

The foliation of the Black Hills slates and schists through the central part of the pre-Cambrian area varies but little in strike and dip. As has been before said, if this were stratification it would require a thickness of sediments of from 20 to 25 miles.* Under such circumstances, when no other structures are found, it is common to assume that such foliation is bedding, as Newton did. This requires either a belief in great thicknesses of sediments or else closely pressed folds, the sides of which are exactly parallel and which have been truncated in such a fortunate position as to cut none of the folds at their turning points. I think it may be stated as a probable general truth, in cases similar to the above, that the structures are more apt to be secondary than original. The strike and dip of cleavage-foliation are a function of the direction of pressure; therefore it has a uniform dip over the

*Geology of the Black Hills of Dakota, pp. 51-52.

entire area in which the direction of pressure is constant, and this oftentimes is large. The folds formed at the same time cause the bedding to have wide variations in dip, unless the squeezing be carried so far as to make the sides of the folds parallel. In this extreme case the cleavage-foliation and stratification would ordinarily be but slightly or not at all discordant.

It is evident, in the Black Hills pre-Cambrian area, that the crust of the earth has probably not been compressed to such an extent as would have been the case had several or many close parallel folds been formed so that the structure would represent bedding. Such a process implies great crustal shortening. Gentle folding, and therefore a small percentage of diminution in area, is often sufficient to thoroughly develop transverse slaty cleavage. Mistaking cleavage-foliation for sedimentation in areas of widely extended parallel structure, where the theory of repeated folds is resorted to, would lead, in most cases, to an over-estimate of the amount of the shortening of the crust of the earth in the supposed folding process.

Correlation.

The slates and schists of the Black Hills—that is, the great mass of the pre-Cambrian rocks of that area, have been seen to be of clastic origin. This suggests the question, do these rocks belong to the most ancient known complex of the earth's crust? In certain localities in the Lake Superior country there are extensive areas of an intricate complex of granite, gneiss, and completely crystalline schists,* older than any rocks which have been shown to be clastic and separated from them by a great unconformity. The larger part of the pre-Cambrian areas of the far west are also of like character. Professors Irving and Bonney † have been inclined to believe that the conditions which produced this wholly crystalline complex have not been repeated in the world's history. It was formerly assumed that schistose structure is a proof of sedimentary origin. It is now generally conceded that this structure is often found in eruptive rocks. This being the case, our own studies have wholly failed to find anywhere in the northwestern country any positive proof of clastic origin for any of these fundamental rocks, although I incline to the belief that certain of them are profoundly modified fragmentals. The old rocks of the Highlands of Scotland belong to the class under consideration. An exhaustive study of this region has been recently made by the Geological Survey of Great Britain. Dr. Archibald Geikie, the Director-General of that Survey, in a recent paper, concludes not only that there is no trace at present of clastic character in any of these rocks, but

* Classification of the Early Cambrian and Pre-Cambrian Formations, R. D. Irving: Seventh Ann Rep. U. S. Geol. Survey, 1888.

† Anniversary Address of the President of the Geological Society of London, T. G. Bonney: Quart. Jour. Geol. Soc., London, Vol. XLII, 1886, Proceedings, pp. [illegible]-112.

that there is no reason for believing, so far as can be discovered, that any of them have ever been clastic. Upon this point one paragraph is so decisive that I quote it in full: *

"Nowhere, however, in the region to which I am referring has any trace of superficial eruption yet been detected. There are no true volcanic ejections, nor any evidence that the rocks, though certainly of eruptive origin, were ever connected with the ordinary explosive operations of volcanic vents. Not only so, but after the most careful search from Sutherland to Galway not a vestige have we yet found of any unquestionable sedimentary material. There are no conglomerates, no sandstones, no shales; nor even any materials that might be supposed to represent these in a metamorphosed condition. Of the actual surface of the earth these Archean rocks afford no recognizable trace. They obviously did not form the superficial layer themselves. They must have lain deep under a cover of other material, under which they acquired their crystalline structure, and by the subsequent removal of which they have been exposed to the light."

So far as I know, the only authorities who at the present time maintain that they have shown that any rocks apparently belonging to this fundamental complex † are water-deposited clastics are Dr. Alexander Winchell and a few of the geologists of the Canadian Survey. Dr. Winchell argues that certain granitic rocks in northeastern Minnesota are conglomeratic, and that the granite and gneiss of that region represent metamorphosed sediments. ‡ The question immediately arises whether these rocks, if really clastic, do not belong to a period subsequent to the fundamental complex.

I will not venture to speak on this point as to the Canadian localities, and Dr. Winchell answers it in the negative for the region described by him. It would, however, seem to be necessary in case an unquestionable water-deposited detrital rock is found, apparently as a part of the fundamental complex, to show by the most positive evidence that it can not belong to a later series.

The presence of bowlder-like forms in various parts of the fundamental rocks of the Lake Superior country have been somewhat widely observed by Irving, Merriam, Bayley, and myself. I have also seen like phenomena in the granites of the Wasatch mountains and in those of the main Colorado range. It has always appeared to me probable that these fragment-like masses in the fundamental gneiss and granite in some cases represent fragments which have been caught in eruptives in their passage to their present position, and at other times represent segregations. Bearing in favor of some such explanation is the extremely irregular shape which these inclu-

* Recent Researches into the Origin and Age of the Highlands of Scotland and the West of Ireland, Archibald Geikie: Nature, Vol. 40, 1889, p. 300.

† By this term I simply mean the most ancient known class of rocks, without implying anything as to origin or expressing any opinion as to whether any portion of it represents the original crust of the earth, or a part of that crust which for the first time has reached the surface.

‡ Conglomerates Enclosed in Gneissic Terranes, Alexander Winchell: Am. Geol., Vol. III, 1889, pp. 153–165; supplement to same, ibid., pp. 256–261.

sions often have. This fact is mentioned by Dr. Winchell in describing his "conglomerates in gneissic terranes."* In Professor Irving's and Mr. Merriam's studies of northeastern Minnesota, they found in several localities peculiar conglomerate-like rocks in the ancient gneisses and granites. Upon a close examination, the bowlder-like forms were found to be mingled with others having the most extraordinarily irregular forms, even grading into elongated dike-like areas. They came to the conclusion that these peculiar occurrences were not water-deposited conglomerates. Extremely irregular fragments are found associated with the well rounded ones in the gneiss and granite of the Colorado range in the neighborhood of Gray's peak. In places the fragments throw out stringers and increase in size until they assume irregular dike-like forms or become apparent layers interlaminated with the coarse granitoid gneiss, just as in Minnesota. An examination of many thin sections from the fragment-like areas of these rocks shows that they are always completely crystalline in character. In mineral composition they are often like the crystalline schists which are cut by the granites. Frequently they differ but little from the granite in which they are contained, with the exception that some one mineral, generally the bisilicate, is much more abundant in the fragment-like areas than in the ordinary rock.†

It would seem that one who maintains that rocks containing well-rounded bowlder-like forms, which sometimes are found intimately mingled with those of extremely irregular shape, occurring in a completely crystalline granular matrix are water-deposited sediments, is bound to explain how a part of them have so perfectly retained their original forms while the others have become so curiously distorted. We have seen how profoundly and yet uniformly the forces of metamorphism have acted in the Black Hills fragmentals; the bowlders are deformed in a common direction. This is well known to be true of the semi-crystalline conglomerates of the Appalachian region, already mentioned (p. 221), as described by the elder Hitchcock.‡ It

* Ibid, p. 155.

† Since writing the above I have received Dr. A. C. Lawson's admirable report upon the Rainy Lake Region of Canada (Annual Report of the Geological Survey of Canada for 1887; Part F). The area is adjacent to northeastern Minnesota. In this memoir Dr. Lawson describes in great detail (pp. 130F–139F) and illustrates by beautiful plates the appearance of pseudo-conglomeratic rocks like those the origin of which has just been discussed. His conclusions are somewhat in the line of those given. He believes that the lower part of the schistose series has been fused and the liquid material thus formed has intruded the unfused schists, sometimes for a considerable distance. Along the zone of contact between the fused and unfused sediments occur these peculiar rocks. It makes no difference in this discussion how the fused rocks originated, if the conglomeratic appearing phases are produced by the interaction of fused and unfused materials and not by the metamorphism of water-deposited sediments.

‡ Geology of Vermont, Edward Hitchcock, 1861. Hitchcock naturally associated with these true conglomerates certain other pseudo-conglomerates of a radically different character, found at Whately, Mass., on Mt. Ascutney, and in Barnett and Granby, Vermont (p. 40). The matrices of these rocks are thoroughly crystalline granular granite, syenite, or porphyry. In these matrices are contained fragments of mica-slate, mica-schist, white quartz, brown sandstone, and hornblende-schist. These pseudo-conglomerates, from recent studies, are probably of Paleozoic age and closely resemble those just described, except that the contained fragments are of a less crystalline character. When their descriptions are closely read it becomes evident that they are eruptives which have caught within them fragments of the rocks through which they have passed (pp. 40–41, 565–566, 624). In these same reports similar occurrences in northeastern Vermont were thus interpreted by Hall

is also the case in the more crystalline parts of the Obermittweida conglomerate* of Germany; and it is very marked in the scarcely less noted localities in Norway described by Reusch †. This regularity in the form of the pebbles and bowlders of these undoubtedly metamorphosed conglomerates is in strong contrast to the conglomerate-like rocks under discussion. In the Black Hills and the other localities mentioned the metamorphism has only gone far enough to produce a finely crystalline schistose matrix, yet in certain cases, the pebbles lack but little of total destruction (p. 215). That the matrix of a fragmental rock could become slowly heated to such a temperature, or be subject to such other conditions as are necessary in order that it could crystallize as a coarsely granular granitoid gneiss or granite, and not at the same time destroy the bowlders and pebbles which it contains, seems to me incredible. The explanation of these rocks and of the interlaminations of granite with slate and schist by metamorphism, implies not only that the fragments and the bands of slate and schist have been able to resist the forces of change during the slow processes which have been sufficient to produce coarsely crystalline material adjacent, but that *in situ* they have continued to resist these forces during all the time required by the matrices to pass once more into ordinary conditions. The processes embodied in such "selective metamorphism" certainly need explanation. If, upon the other hand, the fragments are regarded as caught in an eruptive rock, and the interlaminations of slate and schist with granite are due to the intrusion of the latter, it only necessitates the capacity of the fragments and layers to resist destruction until the heated material has solidified. As the igneous rock has perhaps been removed from any considerable mass of fused material, this process would be a comparatively rapid one. Yet under these comparatively favorable circumstances, instances are too well known to need citation of the partial or complete absorption of fragments caught in dikes or other eruptives. If these fragment-like forms are regarded as segregations or partially absorbed fragments in intrusives, their intermingled regular and irregular forms and frequent lack of definite arrangement present no difficulty.

From the foregoing paragraphs I would by no means be understood as advocating the notion that all the rocks of the fundamental complex are igneous, although in recent years it has been demonstrated that this is the case for many of them. I merely maintain that many clastic rocks which

(p. 719). These pseudo-conglomerates and the interlamination of granite and slate (p. 562) were regarded as evidence that the granites and syenites of Vermont are sediments metamorphosed by aqueo-igneous fusion. It was, however, realized that they were thorougely plastic and acted essentially like eruptives. It would seem to be necessary in each individual case to show, rather than to assume, that the material of the granites and syenites is actually derived from sedimentaries. To extend the significance of metamorphism so as to cover crystalline rocks which have been in a fluid condition is to make it useless for purposes of discrimination.

* Erläuterungen zur geologischen Specialkarte des Königreichs Sachsen—Section Elterlein, A. Sauer, p. 31.

† Die Fossilier führenden Krystallinischen Schiefer von Bergen in Norwegen, H. H. Reusch: Deutsche Aufgabe, R. Baldauf, pp. 16, 22–26, 50–56.

have been believed in the past to be a part of this complex have turned out upon a closer examination to belong to a later series. I have no theory to bring forward to explain the origin of the fundamental complex, but suppose that different parts of it will be found to have diverse histories.

This basement complex is so great in mass and so unique in character that Professor Irving * has insisted that the term Archean should be restricted to it, and that another term should be introduced to cover the clastic series which are later than this and earlier than Cambrian. The great thickness of undoubted clastics belonging here, the United States Geological Survey has collected together under the general term "Algonkian."† This term, thus used, certainly covers independent series of vast thicknesses separated by great unconformities. Using it in this sense, and restricting Archean as above, the slates and schists of the Black Hills of Dakota clearly belong to the Algonkian period.

While this is undoubtedly true, it is to be said that the most crystalline mica-schists and mica-gneisses locally associated with and caught in the granite present a suggestive resemblance on a small scale to the rocks of the fundamental complex.‡ When the whole world is taken into account, it is possible, perhaps probable, that the Algonkian and Archean will be found to be divisible only by a somewhat arbitrary line, just as are all other lines limiting the periods. Even if this should turn out to be the case, the value of the separation upon the basis mentioned is not lessened. It is, however, to be said that there is apparently more chance that a very widespread break will be shown to exist between these two periods than anywhere else in the geological column, with the possible exception of the break at the base of the Cambrian.

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* Classification of the Early Cambrian and Pre-Cambrian Formations, by R. D. Irving: Seventh Ann. Rep. U. S. Geol. Survey, 1888, pp. 448-454.

† The term Algonkian, with the above period significance, was adopted by the U. S. Geological Survey at a meeting of geologists at Washington in February, 1889, called and presided over by the Director. An account of this meeting will be found in the administrative report of the Director in the 10th Annual Report of the Survey. In accordance with the definition decided upon at this conference, Algonkian has already been used in print by Walcott (Stratigraphical Position of the Olenellus Fauna in North America and Europe, Chas. D. Walcott: Am. Jour. Sci., 3rd Ser., Vol. XXXVII, 1889, pp. 383-384). It was first spoken in public, so far as I know, by Mr. S. F. Emmons in a paper upon Orographic Movements in the Rocky Mountain Region, read before the Geological Society of America in New York city in December, 1889. Its use in this sense was objected to by Dr. J. W. Spencer on the ground that he had applied Algonquin to a Pleistocene lake which at one time occupied the area now covered by Superior, Michigan, and Huron (Notes on the Origin and History of the Great Lakes of North America, J. W. Spencer: A. A. A. S., Vol. XXXVII, 1889, p. 199). Algonquin had previously been used by Desor in 1851 to designate "A fresh water deposit extending from the source of the Mississippi as far as the mouth of the Ohio and from Lake Superior to the Falls of Niagara" (On Laurentian as Applied to a Quaternary Terrane, Joseph F. James: American Geologist, Vol. V, 1890, pp. 30-31). Dr. Spencer may maintain with justice that this use is obsolete and that his use of the term is a proper one. Whether this be true or not does not affect the use of Algonkian in an entirely different sense. The latter is an adjective and Algonquin a noun; and, as suggested by Mr. G. K. Gilbert, there are several cases in which the same words in the forms of noun and adjective have been used without confusion for entirely different purposes in geological nomenclature. The two following instances mentioned by Mr. Gilbert sufficiently illustrate this position: Devonian and Devon, the latter applied to a limestone (the Devonian System of North and South Devonshire, H. S. Williams: Am. Jour. Sci., 3rd Ser., Vol. XXXIX, 1890, p. 32); Huronian and Huron, the latter applied to a shale (See Geological Survey of Ohio, Vol. I, 1873, Geology, pp. 107-108; also many other places in this and succeeding volumes). The last case is particularly to the point, as both have been in use for a long time in standard reports and represent rock-masses which differ greatly both as to age and volume.

‡ No one would maintain, I think, that all areas which are crystalline rock-complexes are pre-Algonkian or even pre-Cambrian. The question is whether all pre-Algonkian rocks are completely crystalline—not whether crystalline complex series may not be Algonkian or later in age.

It is also clear that to the Algonkian period belong the series which have been designated as Huronian by the Michigan and Wisconsin geologists, although by no means covering all the rocks here included by the Canadian survey. The question immediately arises whether the modified clastics of the Black Hills can be correlated with the iron-bearing series of Lake Superior. This question cannot be positively answered. Newton, from the uncertain data which at the time of his study was available as to the nature of these Lake Superior rocks, thought it probable that his slate series was their equivalent.* Crosby and Carpenter regard these slates as rather the equivalent of certain of the Taconic schists. As to the probable truth of the latter correlation I have no opinion, because I have no personal familiarity with the Taconic rocks and do not know whether any of them can reasonably be regarded as equivalent to the Lake Superior iron-bearing series. However, the case to-day for placing the Black Hills slates and schists as the possible equivalent of these series is very much stronger than when Newton wrote. Belonging to the Animikie, Penokee, and Marquette series are great thicknesses of mica-slates and mica-schists. These micaceous rocks are certainly of fragmental origin and have a genesis similar to those of the Black Hills. Like them, they are staurolitic and garnetiferous in certain cases. The thick beds of nearly pure quartzite and quartzose conglomerate which occur in the Black Hills are parallelized by quartzites and conglomerates in the Marquette and Penokee areas. Much of the iron-bearing formations of the Lake Superior region have been shown not to be mechanical sediments, but rather chemical or organic sediments which by subsequent alterations have been changed into the various forms now found.† In the Black Hills of Dakota occur considerable beds of rock so like those of the iron formations of Lake Superior that they can hardly be distinguished from them. In the Lake Superior region important beds of iron ore are known in these formations. Such are not yet known to occur in the hills. In the Lake Superior region are vast quantities of basic eruptives which occur in dikes, bosses, and intrusive beds in the fragmental series; similar rocks in similar relative position are again found in the Black Hills. The chief lithological difference between the two regions is the presence in the Black Hills of large masses of granite. The only known parallel to this occurrence in the Lake Superior iron-bearing series is found in one or two unimportant dikes.

This lithological correspondence between the Black Hills rocks and certain of the Lake Superior iron-bearing series is truly remarkable. In cases in which a set of similar conformable formations occur in a definite order in

* Geology of the Black Hills of Dakota, p. 47.

† Origin of the Ferruginous Schists and Iron Ores of the Lake Superior Region, R. D. Irving: Am Jour. Sci., 3rd Ser., Vol. XXXII, 1886, pp. 255-272; The Penokee Iron-Bearing Series of Michigan and Wisconsin, R. D. Irving and C. R. Van Hise: Tenth Annual Report U. S. Geol. Survey (in press).

separate areas in the same geological basin, as the Penokee series on the south shore and the Animikie series on the north shore of Lake Superior, it can safely be asserted that these groups of formations stand as equivalent with each other, at least in a broad way. It cannot be said to be proven that all the Lake Superior iron-bearing series represent the same geological period. All have, however, been placed by most writers as a part of the Huronian, and were believed to be equivalent in a general way by Professor Irving. The Minnesota geologists maintain that the Vermilion iron-bearing series is older than the Animikie. When there is as yet difference of opinion as to correlation of the iron-bearing series in the Lake Superior region itself, no definite statement can be made as to the equivalence to them of so distant a series of rocks as the Black Hills pre-Cambrian. When the structure of the Black Hills rocks is made out it may be ascertained that we have there a set of formations which are not only lithologically alike, but occur in the same order as certain or all of the iron-bearing series in the Lake Superior country. If this proves to be the case, the evidence for placing such groups of rock opposite each other will be very strong indeed. In the meantime, until it is more definitely decided how far lithological correlations can be trusted, it can only be said that the pre-Cambrian rocks of the Black Hills probably are the equivalent of a part or all of the Huronian iron-bearing series of Lake Superior.

Summary of Conclusions.

The Black Hills slates and schists cannot be divided into two series with the surface distribution and upon the lithological differences given by Newton. These two classes of rocks grade into each other.

The sedimentary rocks have all been so metamorphosed that the most marked structures are secondary phenomena, which are entirely independent of original sedimentation. The true bedding is in many places yet discoverable by an alternation of bands which differ in degrees of coarseness and in composition. These bands are cut by the cleavage and foliation. It follows that the thickness of the series is yet to be ascertained.

The largest area of crystalline schists is a broad zone about the granite, striking parallel to and dipping at a high angle away from it. A second important area is about Deadwood.

Corroborative evidence was found of the truth of Newton's conclusion that the main mass of the granite in the sedimentaries of pre-Cambrian age is eruptive. There is every reason to believe that the basic eruptive rocks, such as coarse hornblende-schists and diorites, are even more ancient. They partake to some extent of the structure of the quartzites, slates, and schists in which they are contained, and were regarded by Newton as an integral part of these rocks. They are never found in the granite.

The prominent features of the pre-Cambrian history seem to have been as follows: The original sediments were cut by basic eruptives. They were subjected to great mechanical forces applied in an east and west direction, so as to produce a vertical north and south slaty cleavage before the granite appeared. The resulting folding, as shown by the rows of pebble and true bedding laminæ, is probably complex. After the slaty cleavage and the first metamorphism in the rocks were produced, but before Cambrian time, the granitic eruptions, or more properly intrusions, occurred (for there is no reason to believe that any part of the granite reached the surface) in the southern part of the hills. The resulting contact and dynamic action developed the crystalline schists and schistose structure for the most part parallel to the main igneous mass.

Whether the crystalline schists in the northern hills were formed at this same time by the intrusion of large masses of granite at no great depth from the present surface, or subsequently by the later volcanics, is uncertain. It is probable, however, that the latter rocks have much to do with their schistose character, even if they were not the controlling factor.

Clastic characters are almost indefinitely retained in fragmental rocks, however old and deeply buried, unless they have been subject to dynamic action. Actual movement within a rock rapidly obliterates the evidence of clastic origin.

The most important conclusion from the microscopic study is that the quartzites, quartz-schists, mica-slates, mica-schists, and certain of the mica-gneisses—*i. e.*, the rocks which represent the great mass of the pre-Cambrian area of the Black Hills—are of clastic origin. In the original detritus of the micaceous rocks, feldspar and quartz were the predominant minerals; but the detritus of the quartzites and quartz-schists differed in that feldspar was unimportant. The quartzites developed from the quartzose detritus by the enlargement of quartz-grains and the formation of interstitial independent quartz. In proportion as they are schistose, mechanical deformation with partial destruction of the fragmental particles has occurred. In the most schistose phases, dynamic action has broken down the greater number of the clastic grains of quartz; yet the quartz-schists are as strong as a quartzite of the ordinary type. The fracturing and cementing of the particles of the rigid quartz during the movement within the rock is analogous to ice-flowage in a glacier. In the mica-slates and mica-schists the forces at work and the results produced upon the quartz detritus have been the same as in the quartzites. Simultaneously with this process the detrital feldspar has decomposed into an interlocking mass of mica and quartz. To what extent mechanical movement has helped this alteration is uncertain; but it is known that a like decomposition has occurred in rocks in which mechanical effects are slight, which may have suffered little interior movement, although they have been

under great pressure. In the mica-gneisses, as a farther change, at the time the old feldspars were decomposing, new feldspars of a different character were developing. Evenly granular, typical mica-schists and mica-gneisses have thus been formed from coarse feldspar-quartz detritus. In these final results the positions of the feldspars are marked only by the relative abundance of mica, while those of the clastic quartzes are marked only by a tendency of the broken-down particles of this mineral to be larger and freer from mica than the average of the rock.

The microscopical study brings additional evidence in support of Newton's conclusion that the ferruginous quartz-rocks of the Black Hills are like much of the iron-bearing formations of the Lake Superior region.

In the development of secondary schistose structure, elongation of particles takes place perpendicular to the lines of force, while fracture takes place approximately in the lines of force.

The Black Hills furnishes an admirable instance of the existence of broad belts of slates and schists, the structures of which are thoroughly developed and their directions entirely independent of true bedding.

In the metamorphism of the rocks the sedimentaries and basic eruptives have been affected by the same force. In this metamorphism, both in the fragmental and crystalline rocks, profound mineralogical changes have occurred. A schistose structure has been produced in both. We thus have in the Black Hills crystalline schists of sedimentary and of eruptive origin.

The Black Hills rocks exhibit a remarkable lithological analogy to certain of the iron-bearing series of the Lake Superior region, which in the past have been included under the term Huronian. While this correlation is not beyond doubt, there is no question that these series in common belong to the Algonkian period.

This paper makes no pretension to completeness. To describe in detail the many phases of the rocks of the Black Hills has not even been attempted. The object has been to arrive at the structural relations and genesis of certain among the rocks which occur in the pre-Cambrian area, so far as the material at hand would allow. I cannot close without saying a word in recognition of the work done by Newton. My surprise is not that I find a few things which seem to lead to conclusions different from his, but that he accomplished so much. The area covered in a single season is of vast size. Not only had the geology of the pre-Cambrian rocks to be worked out, but also that of the great fossiliferous series there found. The many problems of geological history presented by the region had to be considered. It was inevitable that the most of Newton's time should be given to determining the boundaries of the periods rather than in describing in detail their characters. Also, to one who first goes into a region, the fossiliferous series

demand the greater attention. Not only this, but at the time of Newton's work the microscope had been little applied to the study of the pre-Cambrian rocks in this country. The geologist of to-day has not only Newton's report to build upon, but those of the army of workers who in the past decade have been engaged in a study of the crystalline schists. In this paper I have necessarily emphasized differences, but I close with a feeling of admiration for the general excellence and fidelity of Newton's report and Gilbert's editorial skill.

Description of Plates.

PLATE 4.

Figure 1.—*Micaceous greywacke. In the ordinary light.*

A large fragmental particle of feldspar has been to a considerable extent altered to biotit quartz. This change has wholly destroyed the exterior of the grain, but the interior appears main as a unit. Pressed close against the feldspar grain upon one side is a large particle of qu The background is finely crystalline quartz and biotite, in which are contained a few larger p cles of quartz.

Figure 2.—*Micaceous greywacke. The same as Fig. 1. In the polarized light.*

The extent of the decomposition of the feldspar to quartz and mica is now appreciated, these two minerals and the residual feldspar making an intricate crystalline complex. The apparently simple elongated quartz-grain of the previous figure is found to have been broken into several parts.

PLATE 5.

Figure 1.—*Mica-slate. In the ordinary light.*

The background consists of mica and quartz, much of the former being muscovite. The larger particles of mica are biotite. A double arrangement of these two micas is very distinctly shown, the cleavage direction of the muscovite being nearly perpendicular to that of the biotite. It is to be noted also that the biotite particles are unusually wide, transverse to the cleavage. This double arrangement of the mica corresponds to the two directions of lamination of the rock as seen in hand specimens. The larger flakes of mica are regarded as having begun to develop at the time of the formation of the first cleavage; when a new force nearly at right angles to the old one set in, and numerous other individuals of mica began to form with their longer axes perpendicular to the new force. The older individuals continued, however, to grow.

Figure 2.—*Muscovite-biotite-schist. In the polarized light.*

This represents one of the typical mica-schists of the Black Hills. The background consists of particles of quartz with their longer axes in a common direction. The mica includes both muscovite and biotite, the folia of which, like the quartz particles, have a very perfect linear-parallel arrangement.

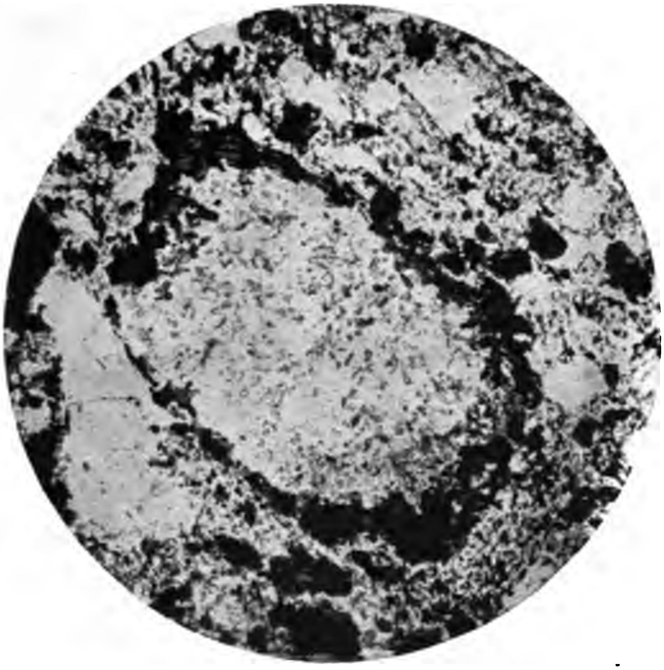

FIG. 1—MICACEOUS GREYWACKE. ORDINARY LIGHT.

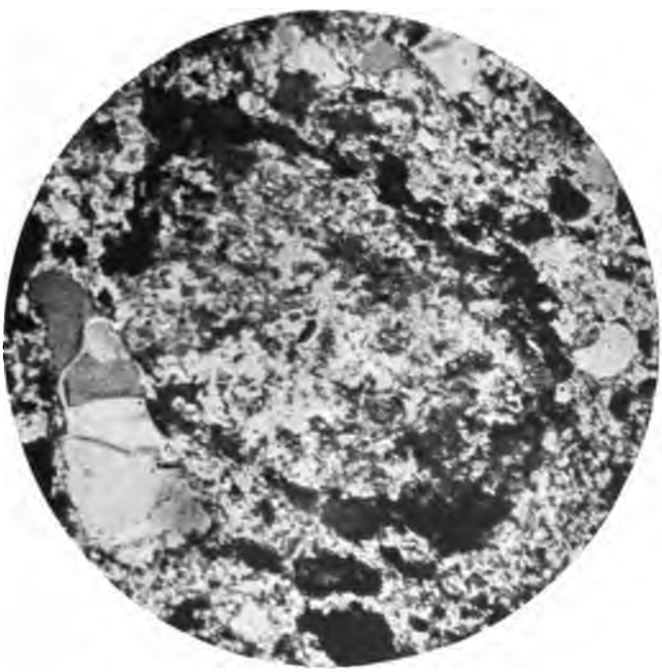

FIG 2—MICACEOUS GREYWACKE. POLARIZED LIGHT.

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FIG. 1—MICA-SLATE. ORDINARY LIGHT.

FIG 2—MUSCOVITE-BIOTITE-SCHIST. POLARIZED LIGHT.

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OROGRAPHIC MOVEMENTS IN THE ROCKY MOUNTAINS.

BY S. F. EMMONS.

(*Read before the Society December* 26, 1889.)

CONTENTS.

INTRODUCTION AND HISTORICAL REVIEW.

That the vast succession of mountain ranges and elevated plateaus and valleys which go to make up the Cordilleran mountain system in the United States must be the final result of a number of orographic movements occurring at different periods of the earth's history was recognized in the earliest geological explorations in that region by Marcou, Newberry, Le Conte, and others. It was not, however, until systematic examination of large areas, both topographical and geological, had been instituted, which permitted the construction of geological maps of a substantial degree of accuracy, that any attempt could be made to determine the number and comparative importance of these movements and their relative position in the structural history of the region. Even then the conditions under which such examinations were conducted, necessitating the covering of large areas in a given time, which time was dependent more upon the geographical extent of the area than upon the complexity or relative importance of its geological structure, did not admit of an exhaustive study, and many significant facts were necessarily overlooked.

It will only be when the whole Cordilleran region shall have been accurately surveyed with much greater detail than has hitherto been practicable that its complete and accurate history can be written. Meantime much additional light can be thrown upon the subject by detailed examination of

specially disturbed districts, where in the limited time at their command the earlier explorers of necessity overlooked or but imperfectly studied many facts of importance in their bearing upon the general orographical history of the region. It has been my lot during the past ten years to make a number of such examinations, incidental to a study of the ore deposits of important mining districts in various parts of the Rocky Mountains in Colorado, and thus gradually to gather together a number of facts bearing upon this subject. Although these facts are not sufficently complete for an exhaustive discussion of the subject, I have been led to attempt to construct from them, and from such information derived from the work of others in the region as seemed pertinent and trustworthy, a slight historical sketch of the orographic movements of the Rocky Mountains between Archæan and Tertiary times, with special reference to two important and hitherto not generally recognized movements, the one during the Carboniferous, the other during the Jurassic epoch.

Many of the conclusions at which I had arrived have to a certain extent been forestalled by my colleague, Dr. C. A. White, in his admirable address on the North American Mesozoic delivered at the last meeting of the American Association, at Toronto, Canada, but as they had been reached independently and from a somewhat different standpoint I have not thought it advisable on that account to modify what I had written.

Before presenting this sketch it may be well to review briefly the principal conclusions that have been arrived at by members of the various geological surveys that have examined this region. They will be taken as far as possible in the order in which the field work of each was done.

Fortieth Parallel Survey.—The orographic movements determined by the geologists of the Fortieth Parallel Survey * are given by Mr. King † as follows:

1. Post-Laurentian.
2. Post-Archæan.
3. Post-Palæozoic.
4. Post-Jurassic.
5. Post-Cretaceous.
6. Post-Vermillion Creek [Wasatch] Eocene.
7. Post-Green River Eocene.
8. Post-Bridger Eocene.
9. Post-Eocene.
10. Post-Miocene.
11. Inter-Pliocene.
12. Post-Pliocene.
13. Faults of the Historical Period.

* Field work, 1867 to 1873, inclusive.
† Vol. 1, Systematic Geology. Washington, 1878, p. 758.

Of these he considers that the work of the first movement was to throw the original crust of crystalline sediments into waves within the present provinces of the Wasatch and of the Rocky Mountains. His post-Archæan movements, which produced the land areas in the Cambrian seas and would now be designated post-Algonkian, extended over the whole breadth of the Cordilleras.

The post-Palæozoic or post-Carboniferous movement produced a continental elevation from the Wasatch westward to longitude 107° 30′. Its effects were most marked at the western edge of this area; and east of it, with the exception of slight unconformity by erosion in the Wasatch,* no direct proof of movement was observed, though there is evidence of shallow water deposition in the succeeding Permian and Mesozoic sediments.

The post-Jurassic movement was likewise considered by him to be mainly confined to the western part of the Cordilleran system, the evidence of unconformable deposition found at that time being too slight to justify the assumption of the general extension of the movement to the east of the Wasatch. It is to this movement that he ascribes the original formation of the peculiar parallel ranges of the geological province of the Great Basin—the Basin Ranges, as they are called—a movement due to tangential compression resulting in contraction and plication † which he distinguishes from the later movements in the same region, presumably Tertiary or later, in which there are few evidences or traces of tangential compression. The principal effect of this later movement has been the faulting and uplifting of irregular areas with little or no attendant plication. Where the effects of the earlier movements were not felt, or have been obscured by erosion and by later sediments and extensive flows of eruptive rock, only those due to the later movement are readily manifested. Hence a number of geologists, whose observations have been principally in such parts of the region, have considered it characteristic of the whole and given the name "Basin Range structure" to this later phase of its orography.

The post-Cretaceous movement was principally manifested east of the Wasatch, the Uinta uplift dating from this period, and the principal elevation of the Rocky Mountain region and the final shutting-out of ocean waters from the whole Cordilleran system east of the Sierra Nevada being due to it.

The subsequent movements during Tertiary and Recent times were foldings, upheavals, and subsidences within a continental area, to be measured not by their relations to sea level, but to that of adjoining land elevations or interior lakes. Thus, those numbered 6, 7, and 8 are shown in successive elevations of the Uinta mountains and in modifications in the adjoining Tertiary lakes whose sediments were largely derived from the abrasion of the broad crest of that range.

* Op. cit., p. 228. † Op. cit., p. 744.

Powell Survey.—Major J. W. Powell,* in his first account of the Colorado river, explains the tortuous nature of the upper portion of its course (the Green river) athwart the Uinta mountains on the hypothesis that the course being already determined previous to the uplift of these mountains its bed was deepened *pari passu* with the slow uplifting of the mountains, furnishing an illustration, which has been widely quoted in text books† and elsewhere, of the slow rate of mountain elevation. This hypothesis involves a conformable deposition of all the beds involved in or affected by the Uinta fold, since it is evident that sedimentation could not be going on in a region through which a river was running and cutting down or corrading its bed. Hence the Uinta fold should have commenced after the deposition of the latest sediments deposited along its flanks—that is, in Tertiary or Recent times. In his second volume, however, he recognizes the fact that the Uinta fold was formed at the close of Mesozoic time, and that during Tertiary times no less than four lakes were successively formed and drained during dry-land epochs, in which 8,000 feet of sediments were accumulated, largely from materials resulting from the degradations of the Uinta fold, and that these sediments did not arch over the crest of the Uinta fold. He found, what had not been observed by the geologists of the Fortieth Parallel, an unconformity by erosion between the Carboniferous and underlying Uinta sandstone, to which he assigned provisionally a Devonian age, showing that a land surface must have existed there during or previous to Carboniferous time. He also recognized, in accordance with the previous observations of the Fortieth Parallel geologists, the existence of a submerged cliff of Eozoic rocks at Red creek (Red Creek quartzites) against which 8,000 feet of Uinta sandstone were deposited. He considers Cenozoic time as the main mountain-building epoch, and regards the Park province or Rocky Mountains as of the Uinta type of structure—that is, that the sedimentary beds now resting against their flanks formerly formed a complete arch over their crests, or that they were completely submerged during the deposition of these beds.

Wheeler Survey.—Of the geologists of the Wheeler Survey,‡ Gilbert recognizes in Utah, Nevada, Arizona, and New Mexico the universality of the unconformity between Archæan and succeeding sediments, whether Cambrian or later. He accepts King's assignment of the Jurassic as the date of original formation of the Basin Ranges, but considers that the Plateau region was submerged from early Palæozoic to the close of Mesozoic time, though subjected to oscillations of level producing changes in depth of waters and consequently in character of sediments. While remarking upon the meager

* U. S. Geol. Survey of the Rocky Mountain Region: Explorations of the Colorado River of the West, Washington, 1875 (field work, 1869 to 1872); Geology of the Eastern Portion of the Uinta Mountains, Washington, 1876 (field work, 1874 to 1875).

† J. LeConte: Elements of Geology. New York, 1878, p. 244. A. Geikie: Text book of Geology. London, 1882, p. 920.

‡ Explorations West of the 100th Meridian: Vol. III, Washington, 1875 (field work, 1871, 1872, and 1873); vol. III, Supplement, Washington, 1881 (field work, 1878 and 1879).

representation of the Upper Silurian and Devonian both in fossils and in strata, he finds no evidence to prove that the region was lifted above water during these times, but considers that the general movement of the land during Palæozoic time was a subsidence, and that where Carboniferous limestone rests directly upon the Archæan there were islands in the early Palæozoic seas which became submerged in Carboniferous time.

J. J. Stevenson, in the course of his explorations in Colorado and New Mexico in 1873, noted several unconformities and drew the following conclusions:

"The Rocky Mountain system, therefore, is the result of four especially marked upheavals, the first, at the close of the Carboniferous; the second, at the close of the Trias; the third, at the close of the Cretaceous, and the fourth, during the Tertiary. Of these, the first and the third were the most general in their effect."

He also recognized the unconformity of overlying beds with the Archæan. In his subsequent more detailed work in southern Colorado and northern New Mexico he does not seem to have found reason to modify these general conclusions.

Hayden Survey.—The beautiful geological atlas of Colorado,* showing the result of the combined labors of the various members of the Hayden Survey, furnishes a most valuable record of the geology of the Rocky Mountain region. Unfortunately no systematic discussion of their field observations has yet been made to present the final orographical conclusions which would be drawn with the consensus of all who were engaged in the work. In the absence of such a discussion inferences must necessarily be drawn from the graphic representation of facts given by the maps, where personal verification in the field has not been possible. Such verifications as have been made have proved the substantial accuracy of the geological outlines laid down on these maps, except in southeastern Colorado and in the San Juan mountains, where at the various points examined the facts of nature show such wide divergence from these outlines, as laid down by Mr. Endlich, as to throw serious discredit upon all of his field work.

Dr. A. C. Peale, of this Survey, has since summarized the results of his own observations in Colorado as follows: †

"1st. In very early times in Colorado there was Archæan land rising above the Palæozoic sea. As the Carboniferous age progressed this land diminished by encroachment of the sea, due to subsidence of the land. This subsidence continued through Triassic, Jurassic, and Cretaceous time into the early Tertiary.

"2nd. At the close of the Lignitic, there was a physical break followed by subsidence (at least locally), and subsequently by elevation after the deposition of the Miocene strata.

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* Field work 1873, 1874, 1875, 1876.
† Amer. Jour. Sci., 3d Ser., Vol. XIII, Mar. 1877, p. 181.

"3rd. The elevation of the Rocky Mountains, as we now see them in Colorado, is the result of an elevation commencing in early Tertiary time and continuing through the period, accelerated perhaps at the close of the Lignitic and after the deposition of at least lower Miocene strata."

This was written at the time when Dr. Peale, in accordance with the views of his chief, Dr. F. V. Hayden, regarded the Lignitic (Laramie) as of Tertiary age.

Black Hills Survey.—In the Black Hills of Dakota * Newton and Jenney recognized two distinct series of crystalline schists, with some faint evidence of unconformity between them. The great breaks determined by them were between these crystalline schists and the Cambrian (Potsdam sandstone). More recently W. O. Crosby† has found evidence of an uplift of the region at the close of the marine Jurassic.

Colorado Plateau Region.—Gilbert, in his Geology of the Henry Mountains,‡ remarks on the physical break at the close of the Cretaceous, and notes three unconformities by erosion, one at the close of the Carboniferous and two within the series called by him Jura-Trias.

In the preface to Captain Dutton's work on the High Plateaus,§ Major Powell states with regard to the Plateau province—

"A marked unconformity exists between the Silurian and Devonian rocks; another between the Devonian and Carboniferous; another, but not so well marked, between the Carboniferous and Mesozoic, and lastly an unconformity between Cretaceous and Tertiary is usually well defined."

In the region of the Grand Cañon of the Colorado,|| Captain Dutton notes, besides the universal unconformities at the close of the Archæan and the Cretaceous, that the Carboniferous rests unconformably upon the Silurian or Devonian, as the case may be. He also finds unconformities by erosion between Carboniferous and Permian, between Permian and Trias, between Trias and Jura, and between Jura and Cretaceous. He considers that the Carboniferous was deposited in deep waters, but that during the Permian and Mesozoic, shallow-water conditions prevailed; also that the Eocene was a fresh-water deposit, that a slow elevation began about the middle of this epoch, and that the Colorado river commenced as a drainage channel of the Eocene lake in early Tertiary times, gradually eating its way back until it reached its present extension, and cutting across any elevations produced during subsequent movements as they rose without changing its already determined course.

I find it difficult to reconcile my own observations in the Uinta mountain

* Geology of the Black Hills of Dakota. Washington, 1880 (field work, 1876).
† Proc. Boston Soc. Nat. Hist., Vol. XXIII, March, 1888.
‡ Washington, 1877, p. 10 (field work, 1875 and 1876).
§ Geology of the High Plateaus of Utah. Washington, 1880, p. vii (field work, 1875, 1876, and 1877).
|| Mon. II, U. S. Geol. Survey: Tertiary History of the Grand Cañon. Washington, 1882 (field work, 1879–1880).

region with the views of either Powell or Dutton, with regard to the determination of the course of the Colorado river; and I am inclined to think that future investigation will prove that they have placed it at too early a date. I have already shown * that the Wyoming conglomerate (Bishop Mountain conglomerate of Powell), which has escaped erosion along the flanks of the Uinta mountains, is so situated as to prove that it must once have extended over the entire eastern end of the mountains through which the cañon of the Green river is now cut, forming a nearly level surface at an altitude corresponding to a present elevation of between 9,000 and 10,000 feet, and that the river must have initiated its present meandering course over this surface as a superimposed valley. This conglomerate is considered by all who have examined the region to be of very late age, either Pliocene or Quaternary, though no fossils have yet been found in it. It is everywhere horizontal and undisturbed, showing no stratification planes, but at one exposure shows a thickness of 200 feet of rounded pebbles derived from the Uinta quartzite, cemented into hard rock by an abundant lime cement. The situation of its remaining exposures is such that I cannot conceive of the possibility of the existence of the cañon of the Green river during its formation. While in the Plateau province south of the Uinta mountains no beds have yet been discovered that are known to be of later than Eocene age, the region has not yet been examined with sufficient detail to make it certain that they have not existed there. Such beds would have been the first to be affected by the enormous erosion to which the entire region has been subjected, and the present limited extent of the Wyoming conglomerate (which has doubtless been exceptionally protected by its position along the flanks of the range), as compared with that it must once have had, proves how thoroughly such recent deposits could have been carried away by recent erosion.

In more recent observations in northern New Mexico,† Captain Dutton found upper Carboniferous beds resting directly on the Archæan in the Zuñi plateau and the Nacimiento mountains, the Cambrian, Silurian, and Devonian being wanting.

In more detailed studies of previously examined sections in the Grand Cañon of the Colorado, Mr. C. D. Walcott ‡ has recognized a great thickness of comparatively unaltered sandstones, shales, and limestones (the Chuar and Grand Cañon series), which he considers of Algonkian age, and which rest unconformably upon sandstones and eruptive granites of undetermined age. A distinct unconformity of angle exists between the Algonkian and upper

* Descriptive Geology: Vol. II, Fortieth Parallel reports. Washington, 1887, pp. 194 and 205 (field work, 1871).

† Mount Taylor and the Zuñi Plateau: 6th Ann. Rep. Director U. S. Geol. Survey. Washington, 1885, p. 132 (field work, 1884).

‡ Am. Jour. Sci., 3d ser., vol. XX, p. 221; vol. XXVI, p. 437; vol. XXVIII, p. 431; vol. XXXII, p. 154; vol. XXXV, p. 399; vol. XXXVII, p. 374; vol. XXXVIII, p. 29; and Bull. U. S. Geol. Survey, No. 30, 1886, p. 15.

Cambrian (Tonto beds). He also observed unconformities by erosion between, *first*, the upper Cambrian and Devonian ; *second*, Devonian and lower Carboniferous ; *third*, upper Carboniferous and lower Permian ; *fourth*, lower Permian and upper Permian. A similar unconformity between Algonkian and upper Cambrian was observed by him in Llano county, Texas.

With regard to the Mesozoic, Dr. C. A. White * first made the following suggestion, based on the finding of fresh-water Jurassic fossils in Colorado and Wyoming:

> "In conclusion, I think it may be safely assumed that the great inland portion of our continent was not so permanently the seat of oceanic waters during the Mesozoic times as has been generally supposed."

I have already in a previous publication stated my belief that the Archæan areas in Colorado occupy the sites of mountain elevations that were uplifted above the ocean in post-Archæan time, and which in a more or less modified form have constituted land areas ever since—that is, that in the times of the greatest general depression of the region they were never so completely submerged as to admit of continuous sedimentation over them, but some mountainous islands always existed, from the abrasion of which the sediments in the adjoining seas were formed. This view is opposed to that held by the late Dr. F. V. Hayden, and also to that expressed by Major J. W. Powell in his geology of the eastern Uinta mountains,† both of which involve a former complete arching over of the present crests of the mountains by the strata now upturned along their flanks. It had, however, already been advocated by Mr. Clarence King ‡ in his Systematic Geology, and by Dr. A. C. Peale § of the Hayden survey.

The necessity of this view was impressed upon me by the structural conditions of the beds resting on the eastern flanks of the Colorado range long before I had made any special studies of Colorado geology, and my subsequent field work there has only served to confirm its general correctness by the persistent evidence it has afforded of the littoral character of the sediments along the assumed shore-lines, which changes rapidly as they are left; and by the character of much of the organic life whose remains, found in these sediments, indicate the vicinity of land areas, and add to the impossibility of explaining in any other way the peculiar stratigraphical relations observed.

In tracing the effects of orographic movements upon the earth's crust, a marked contrast is noted between the regions of violent disturbance, generally mountainous areas, and those in which the strata show little change from the horizontal position in which they were originally deposited, which

* Bull. U. S. Geol. Survey, No. 29, 1886, p. 14.
† Geology of the Eastern Portion of the Uinta Mountains. Washington, 1876, p. 26 et seq.
‡ Fortieth Parallel Reports, vol. I, 1878, pp. 128, 533, 729.
§ Am. Jour. Sci., 3d. ser., vol. XIII, 1877, p. 181.

are characteristically represented by the great plain areas of the present day. In the former, the strata show the effects of powerful and repeated tangential compression, not only in their steeply inclined positions and sharp folds and faults, but in the frequent and marked angular unconformities between beds deposited before and after an orographic movement. In the latter, on the other hand, the inclinations of the strata diverge but little from a horizontal position, the folds are but gentle undulations or monoclines broken by faults of moderate displacement, and no angular discordances between successive strata are to be observed, whatever orographic disturbance may have intervened between the times of the respective depositions.

Nowhere is this change of condition more marked and sudden than in the Rocky Mountains of Colorado. In leaving a mountain area one may pass in a mile or two from steeply upturned and even reversed strata, showing evidences of violent movements accompanied by long periods of erosion before succeeding beds were deposited, to an adjoining plain where the same beds rest in horizontal position and in perfect stratigraphical accordance one over the other, and where the only evidence of erosion on the beds below the horizon of the movement may be a variation in their aggregate thickness. Not only is this true of the outer flanks of the mountain ranges, but it can also be observed to hold good for many of the interior depressions which would seem to have been either valleys or arms of the sea throughout the various phases of the geological evolution of the region.

It is evident, therefore, that except in highly disturbed regions actual evidence of unconformity must be extremely rare, the parallel succession of beds after an orographic movement, or parallel transgression as it is designated by European geologists, being far more common than actual discordance of stratification; but even in highly disturbed districts, I have found that a very marked discordance of stratification is not always shown by an actual angular unconformity along the line of dip, but that its evidence is readily found only in variations in the strike between beds deposited before and after an orographic movement, or, what amounts to the same thing, by the observation that the later beds rest at different points upon different horizons of the earlier series of beds. The explanation of an extreme case of conformity in angle of dip, combined with the greatest variations in strike, which has come under my observation, is very readily apparent and, with local modifications, is doubtless applicable to all similar structural phenomena. In the given case, the beds already deposited were by an orographic movement thrown into a series of folds whose axes had a general east and west direction. After the crests of these folds had been planed off by erosion, a second series of beds was deposited upon them, producing a complete succession of beds with no discrepancy of angle, along an east and west line in the troughs of the synclinal folds, but with gaps of varying width in the succes-

sion of beds on the crests of the anticlinals. In the following movement both series were thrown into a series of folds the prevailing direction of whose axes was north and south, or at right angles to the preceding folds; and after these folds had been eroded, in the beds left standing with a steep western dip, the evidence of the earlier folds is found only in their irregularly-waving line of strike as compared to the comparatively straight one of the later beds, while the angle of dip in the two series is in many cases perfectly conformable, and what variations may exist in other cases is generally undistinguishable, either from its slight amount or from the unfavorable position of the exposures.

In weighing the evidence for or against an orographic movement in a given region it would seem, therefore, that the positive proof afforded by one or two instances of unconformity should overbalance the negative testimony of many instances of apparent conformity.

In endeavoring to trace out the orographical history of the Rocky Mountain region I have followed the method of reconstructing in my mind the probable outlines of its various land-masses when a period of sedimentation began after the close of an orographic movement, and the changes produced in those outlines by each succeeding movement.

Rocky Mountain Region.—The mountain area which is referred to in this paper as the Rocky Mountain region, is a north and south belt about 150 miles in width, extending from northern New Mexico through the state of Colorado into southern Wyoming, a distance in round numbers of about 400 miles. As the land areas at the close of the successive movements especially referred to correspond more or less closely to the areas of the principal mountain ranges, areas whose general lines of uplift it may be assumed were determined very early in its history, perhaps at the close of the Archæan, they will be referred to as islands under the names that are now applied to the ranges. Their general disposition is as follows: The mountain uplift fronting the Great Plains, which as a whole has a meridional trend, is divided by depressions having a general northwest trend into three more or less distinct ranges, whose northern continuations, leaving the line of uplift which fronts the Plains, trend to the northwest and thus produce a structure *en échelon* for the whole system. The northern and most extensive of these, the Colorado range, extends from Pike's peak northward to the Colorado state line and then splits into two distinct uplifts on either side of the broad elevated valley known as the Laramie plains. The eastern of these uplifts, the Laramie hills, was a submerged reef in Palæozoic times and has a somewhat broken connection by small projections of Archæan exposures with the Black Hills of Dakota. The western uplift, known as the Medicine Bow range, trends northwestward between the Laramie plains and the North park, at one time having been connected with the northern end of the Park

range or Grand Encampment mountains. It disappears beneath the present east and west depression of central Wyoming; but a submerged line of uplift, proving a possible connection with that of the Wind River mountains, is found in the Archæan exposures of Rawlins peak and the Sweetwater mountains.

Immediately west of the Colorado mountain mass are the broad valley depressions of North, Middle, and South parks.

Southwest of Pike's peak and separating the Colorado range from the Wet mountains is a bay-like depression extending northwestward from Cañon City toward the southern end of the South park.

The Wet mountains form the mountain front from Cañon City south to Huerfano park, and have a small depression or park to the westward, known as the Wet Mountain valley, which is of less orographical significance than those already mentioned, having once probably been part of an elevated region, brought down to its present position by faulting and erosion in more recent times. The northwestern continuation of the Wet mountains has also lost its former topographical importance, but is recognized geologically in the Archæan area along the Arkansas river, west of the Royal gorge.

Huerfano park is a second bay-like depression, which, if extended to the northwest, would merge into the Wet Mountain valley. It separates the Wet mountains from the Sangre de Cristo range, which, rising gradually from the plains of New Mexico, forms the east front of the Rocky Mountains as far north as Huerfano park, and then trends northwestward, forming the western boundary of that park and of the Wet Mountain valley in the same general line of uplift as the Sawatch range.

The original Sawatch uplift, now divided by the upper Arkansas valley into the Sawatch and Mosquito ranges, formed the earlier western boundary of the South park depression, as the Mosquito range does to-day.

The western boundary of the Middle and North parks is formed by the Park range, a line of uplift also having a northwesterly trend parallel to that of the Sawatch and set off *en échelon* a little to the northeast of it. Its northwestern end is known as the Grand Encampment mountains, and the southern continuation, which at times has been separated from it, is called the Gore mountains.

To the southwest and west of the Sangre de Cristo is the great valley depression of the San Luis park, on the same general meridian with the other parks, but geologically distinct in that it is probably of more recent formation, since there is no evidence that Mesozoic sediments were ever deposited in it. To the northwest, and separating it from the head of the Gunnison and lower Grand rivers, is a broad area of moderate elevation now buried beneath extensive bodies of igneous rocks. But little can now be learned by actual observation of the structure of the underlying rocks of

these two areas, owing to their almost unbroken covering of alluvial and eruptive material; but, as will be seen later, it may be inferred from the structural conditions of the adjoining regions on the north and east that another elevated island once occupied some portion of it, possibly connected with the southern end of the Sawatch island, which has disappeared under the influence of erosion or local subsidence.

A western meridional line of elevation beyond those above mentioned is formed by the San Juan mountains west of the San Luis park, the Elk mountains west of the Sawatch range, and the White River plateau. The two latter are closely connected together, but are separated from the greater uplift of the San Juan mountains by the broad east and west depression of the Gunnison valley. This line of elevation, as compared with that to the east, is characterized by having been the scene of intense eruptive activity in late Mesozoic and Tertiary times; and the same evidence of eruptive activity is seen on the same north and south line in the Elkhead mountains on the western flanks of the Park range.

It is only of the beds deposited during and subsequent to Cambrian times that the outcrops are exposed in sufficient continuity to justify an attempt at differentiating the land areas around which they were deposited.

Pre-Cambrian Land.

Of the extensive series of clastic sediments which the investigations of Irving and his colleagues in the Lake Superior region have shown must have been deposited upon the Archæan basement of distinctly crystalline rocks previous to the earliest Cambrian, for which the general term Algonkian is now proposed, only a few isolated exposures have yet been discovered in the Rocky Mountain region, and these have not been sufficiently studied to attempt any correlation between them. With regard to the earlier land areas, therefore, only a few general conjectures can be formed.

Algonkian Exposures.—Between the western Archæan continent (of which, as King has shown, the present Wasatch uplift must represent the eastern shore-line) and the Archæan islands of the Rocky Mountain region, it may be assumed that a general depression existed in Algonkian time commensurate with that which has obtained in later periods. The Grand Cañon and Chuar series, which Walcott has assumed to be of Algonkian age, and on the upturned and eroded edges of which rest upper Cambrian beds, are on the general north and south line of the Wasatch uplift. The only other known pre-Cambrian exposure in this depression is that of the Red Creek quartzites of the eastern Uinta mountains, which were classed as Huronian by the Fortieth Parallel geologists, and probably belong to one of the Algonkian series. They serve to show that the Uinta uplift, which is of post-

Cretaceous age, probably owes its position to a pre-Cambrian ridge which acted as a buttress or *point d'appui* to the forces of compression which produced this most remarkable and exceptional anticlinal fold of 30,000 feet of practically conformable beds. The series of schists, slates, and quartzites of the Black Hills, which have hitherto been classed as Archæan, are probably of Algonkian age also.

In the Rocky Mountain region Mr. Arnold Hague found a considerable thickness of quartzites resting on the Archæan in the Medicine Bow range at its northern extremity, and an isolated patch of quartzite and conglomerate is known to exist on the east flanks of the Colorado range near Boulder. In the hills east of the Arkansas river at Salida and south of the South park, Mr. Whitman Cross discovered a thickness of about 10,000 feet of slates and schists entirely distinct from the Archæan and probably unconformable with it. On the north slope of the San Juan mountains near Ouray, I have found over 10,000 feet of closely folded quartzites, conglomerates, and slates of pre-Cambrian age, and believe that the Quartzite peaks in the southern portion of this region are probably composed of the same series of rocks.* Quartzites have also been noticed connected with the Archæan of the southern end of the Sangre de Cristo range which may on general grounds be assumed to be the remnants of some Algonkian beds.

While these various exposures are too isolated and have been too little studied as yet to justify an attempt at correlation between them, they are easily distinguished from the Archæan or basement rocks even when not found directly associated with them. The latter, so far as the great areas exposed have been studied, are distinctly crystalline, consisting mainly of granites, gneisses, mica and hornblende schists, with none of the limestone or apparently fragmentary beds which confuse the student of Archæan developments in the east; while in the former, secondary alteration is either very slight throughout the series or limited to certain beds, so that there can be no doubt of their clastic or mechanical origin.

The character of the material of which they are composed and their great thickness show that they result from a long-continued abrasion of high Archæan land-masses in their near vicinity. It is to be noted, moreover, that all the Algonkian exposures, with the exception of that near Salida, are on the outer flanks of the area which has been designated the Rocky Mountain region. Their beds are steeply upturned or sharply folded, and all Cambrian or later sediments rest unconformably upon them, as upon the Archæan; hence there must have been at least two and possibly more orographic movements between Archæan and Cambrian times.

Cambrian Exposures.—At the base of the Palæozoic section in the Wasatch mountains, as exposed in Big Cottonwood cañon, are 12,000 feet of quartzites

* This opinion is confirmed by Mr. Van Hise, who has visited this region during the past summer.

and slates, resting unconformably on the granite body of Little Cottonwood cañon and upon a series of schists which form the western flank of this body. These were classed by the Fortieth Parallel geologists as Cambrian, while the schists were assumed on lithological grounds to correspond with the Red Creek quartzites of the Uinta mountains. In my study of the Uinta range in 1871 I found only upper Carboniferous beds, as determined by their fauna and their lithological correspondence with already defined horizons in the adjoining Wasatch range, and considered that the great thickness of quartzites, conglomerates and shales underlying them in apparent conformity and forming the core of the range belonged to the silicious or middle member of the Carboniferous. Powell, however, having found, in the cañon of the Green river at the eastern end of the mountains, an unconformity by erosion between the upper and lower portion of these sandstones, I assumed that the lower portion, the Uinta sandstones, must correspond to the Cambrian quartzites of Big Cottonwood cañon.* In his later examination of the Big Cottonwood section, Mr. Walcott found lower and middle Cambrian faunas in the upper 2,000 feet of the Big Cottonwood quartzites, and classed the lower 10,000 feet as Algonkian. According to this classification the Uinta sandstones would probably be of Algonkian age, but of a later period than the Red Creek quartzites.

In the Grand Cañon region, throughout the Rocky Mountain region, in the Black Hills of Dakota and, so far as known, in Texas, New Mexico, and Arizona, only upper Cambrian beds were deposited. It must therefore be assumed that during early and middle Cambrian times, while the Big Cottonwood beds were being deposited, these regions were elevated above the ocean; but that a progressive subsidence was going on which initiated a cycle of deposition in the Rocky Mountain region extending from upper Cambrian to middle Carboniferous time.

The beds deposited during this interval are of extremely limited thickness as compared with that of corresponding horizons in Utah and Nevada, no exposures thus far examined showing as much as one-tenth of the thickness represented in the Wasatch section. Their fauna also has thus far proved to be extremely meager. A fairly uniform succession in character of sediment is observed throughout the region, the Cambrian commencing with a fine basal conglomerate indicative of an advancing shore-line, followed by varying thicknesses of sandstones, which pass upward through calcareous sandstones and shales into silicious limestones in the Silurian and pure dolomites or limestones in the lower Carboniferous, with a somewhat abrupt passage into clays and sandstones above, showing evidence of shallow-water deposition.

Such palæontological evidence as has been obtained proves the existence

* Fortieth Parallel reports, Vol II p. 199.

of faunas characteristic, in other regions, of upper Cambrian, of some horizons of the Silurian, of lower Carboniferous, and of the Coal Measures. From time to time individual forms, apparently indicative of a Devonian age, have been found; but in every case a more exhaustive examination of the locality has shown their association to be overwhelmingly Carboniferous or Silurian. The Devonian, therefore, seems to be wanting in the Rocky Mountain region, as it has thus far been found to be in New Mexico, Texas, Arkansas, and the Black Hills. To account for its absence in the latter region, Mr. W. O. Crosby * has advanced the ingenious theory that, in the cycle of deposition succeeding the Cambrian, the ocean had in Devonian time reached the abyssal depth at which, according to Murray, sedimentation is no longer possible. While I must admit that evidence of shallow-water deposition is less conclusive in this interval than in those which succeeded, and that portions of the Colorado islands were then submerged which were not subjected to sedimentation during the succeeding intervals, I am unable to accept this explanation for the Rocky Mountain region, and am more inclined to attribute the absence of Devonian to a partial recession of the ocean. The direct evidence of such recession is, it must be confessed, as yet very slight, being limited to an unconformity by erosion between Silurian and Carboniferous, observed in a single locality only,† and to the existence of a thin and not always persistent sandstone between Silurian and Carboniferous limestones.

This supposition corresponds better with the course of events on the eastern continent as recently traced out by Prof. J. D. Dana.‡ The break which he shows to exist at the close of the Lower Silurian does not correspond exactly in geological succession with the gap which appears to exist in the Rocky Mountain region; but the exact position of this gap in the geological column is not yet determined. It is quite possible, moreover, that the elevation of land may not have been strictly contemporaneous in both continents, and that the succeeding subsidence which allowed the reoccupation of the region by ocean waters may have proceeded more rapidly in the one than in the other.

Early Palæozoic Land.

The land areas that existed during this time, or rather the degrees to which the present elevated regions were submerged so as to admit of sedimentation, were somewhat as follows:

Colorado Island.—At the north the Laramie hills extension of the Colorado range was submerged beyond the state line, and the shore-line extended

* Proc. Bos. Soc. Nat. Hist., vol. XXIII, March, 1888.
† Monographs U. S. Geol. Survey, No. XII, 1886, p. 56.
‡ Bull. Geol. Soc. Am., vol. I, 1889, p. 36.

continuously along the flanks of the Medicine Bow range and across its extremity to the Park range, but the ocean waters did not penetrate the North and Middle parks which, up to post-Cretaceous time, formed a single connected valley. On the east the shore-line probably reached higher and further westward than the present hogbacks. Pike's peak stood out as a promontory, or possibly as an island, the shore-line extending across the ridge to the north of it into the bay now occupied by Manitou park, while to the southwest the waters of the Cañon City bay covered Webster park and portions of the ridge through which the Royal gorge of the Arkansas is now cut, and northwestward may have penetrated the South park depression. The main connection of South park with the ocean was, however, from the northwest around the northern point of the Sawatch uplift and across what is now the northern portion of the Mosquito range.

Further north the western shore of the Colorado island was formed by the Park range, so that its general outline was triangular with apex toward the south and its width about 100 miles at the broadest part.

Sawatch Island.—To the west of the South Park bay was the Sawatch island, which included the west flanks of the present Mosquito range and the upper valley of the Arkansas. The area of its present Archæan exposures within the fringing reef of Cambrian quartzites is about 100 by 30 miles. It was undoubtedly smaller at the time when these were deposited, but their outline probably preserves the general shape of the original island, as they resist erosion even better than the Archæan rocks.

Southern Areas.—With regard to the southern portion of the region, it is difficult to reconstruct the probable distribution of land and sea at this time, partly on account of the uncertainty with regard to the outlines given on the Hayden map, and partly because observers have not hitherto discriminated between upper and lower Carboniferous horizons.

South of the latitude of Cañon City and of the southern end of the Sawatch island, the only region where the lower Palæozoic rocks can with certainty be said to have been deposited is in the western portion of the San Juan mountains. Along the Sangre de Cristo range the conglomerate series of the upper Carboniferous is known to rest upon the Archæan in many places, and at the southern end of this uplift Stevenson found lower beds which may belong to the earlier series; but in the present state of our knowledge of the Carboniferous fauna of the Rocky Mountain region the palæontological evidence is not decisive. By analogy it would seem probable that the two exposures of Carboniferous on the east flanks of the Wet mountains belong to the lower series. On the other hand, in the outlying regions of the Uncompahgre plateau, in western Colorado south of the Grand river, and at the Zuñi and Nacimiento mountains in northern New Mexico, upper Carboniferous beds rest directly upon the Archæan, which is in so far an evidence of

land areas there during Palæozoic time. As will be seen later, the elevation which accompanied an orographic movement did not affect the whole area uniformly, but some regions were raised more than others, and indeed there is some evidence to prove that some portions of the area were actually depressed while others were being raised. In a general way, therefore, it may be said of the southern area that the distribution of land areas was probably somewhat more widely spaced than in later times, and that interior depressions existed that were afterwards raised above ocean level, and even became parts of prominent mountain masses as the outlying land-masses were depressed.

The Late Palæozoic Movement.

The existence of land areas toward the close of Palæozoic time has been frequently suspected by western geologists from the evidence of shallow water and shore-line conditions in the beds which have been considered upon somewhat meager and often conflicting palæontological evidence to belong in different localities to the upper Carboniferous, Permian, or Trias; but, so far as I know, no actual unconformity has hitherto been observed. In the summer of 1882 I first noticed what seemed conclusive evidence of the existence of such an unconformity in the Elk mountains, but it was not until two years later that actual field work with my assistants, Messrs. Cross and Eldridge, enabled me to fix its horizon as in the middle or upper part of the Carboniferous.* Since that time I have found such corroborative evidence of its existence in various parts of the Rocky Mountains as justifies the conclusion that a general orographic movement took place throughout this region, whose effects may probably be found to have been felt beyond it. It is a movement that is in many ways difficult to define. Firstly, on account of the wide range of most of the abundant molluscan species which are found in Carboniferous beds, owing to which palæontological evidence by itself is thus far of but little value in determining the relative position of any beds except those at the two extremities of the series. Further, because the dynamic disturbances that accompanied the movement were very unequally distributed, and their effects are to be observed, as a rule, only in regions which were again violently disturbed during the succeeding movement, where they were consequently much obscured. Its determination as occurring in middle or late Carboniferous time has, therefore, necessarily been founded mainly on the stratigraphical relations and lithological character of the beds.

That it was not earlier than middle Carboniferous is proved by the finding

* A notice of this, and of the Jurassic unconformity observed in the same region, was published in the Sixth Annual Report of the Director of the U. S. Geol. Survey, 1885, p. 64.

of Coal Measure fossils in the limestone pebbles that in some regions form a characteristic feature of the conglomerates deposited immediately after the movement. On the other hand, the thickness of beds deposited after the movement, presumably of Carboniferous age, is far greater than that of those beds deposited before it; but as these are of extremely coarse material, evidently deposited during the rapid abrasion of high land-masses in comparatively close proximity, it is evident that the mere thickness of the deposit is not a very reliable time-gauge.

During this movement some areas were uplifted and eroded in such a way that the later sediments overlapped the upturned edges of the earlier beds. In others, for instance around the shore-line of the Sawatch, the elevation was of such a nature that the succeeding sediments were deposited in perfect conformity, and no evidence of erosion has been detected between the two series of beds, though land plants and limited developments of coal or of bituminous shales are found at certain horizons.

Perhaps the most remarkable feature of the sedimentation which followed the movement was the great thickness of very coarse conglomerate along the present Elk mountain and Sangre de Cristo ranges, reaching a thickness of 3,000 to 6,000 feet, which are not found at all on the east front of the Colorado and Wet mountain ranges. In the Elk mountains the pebbles are mostly of limestone, which are entirely wanting at corresponding horizons along the adjoining Sawatch range. In the Sangre de Cristo range they are mostly of gneiss and granite, with some limestone pebbles; the fragments of Archæan rocks in the beds opposite the Wet Mountain valley are often as much as 25 or even 50 feet in diameter, and must either have dropped from adjoining steep cliffs or have been carried out into the sea by ice. To account for the formation and present stratigraphical relations of the Elk mountain conglomerates it is necessary to assume that during the movement a land area was uplifted to the south of that region, from which the earlier Palæozoic beds were mostly denuded, and whose original outlines or area can no longer be determined.

The sediments that were deposited between this and the succeeding movement near the close of the Jura were largely conglomerates, with a few mud shales and occasional thin beds of limestone. The Triassic "Red Beds" near the top contain finer grained sandstones and some clays. Gypsum is found locally developed at various horizons.

In most of the beds deposited during this interval it has hitherto been impossible, in the absence of decisive palæontological evidence, to determine how much of the entire series is represented. Only the Carboniferous beds have been found to contain molluscan remains, and these are wanting in the coarser grits and conglomerates. The evidence afforded by plant life has thus far proved to be somewhat meager and uncertain. In outlining geolog-

ical divisions on maps, therefore, too much reliance has necessarily been placed on distinctions derived from the character of the sediments. While that of the upper part of the Trias seems to be persistent over this and the adjoining regions, the earlier sediments only show a general prevalence of conditions of rapid abrasion and shallow-water conditions. Whether the Permian beds, recognized in the Wasatch and Grand Cañon regions on the one side and along the borders of the eastern continent and in Texas on the other, are represented here seems still uncertain. Plants of Permian facies have been found, but they are often associated with a Carboniferous fauna. It is possible that the general elevation, which the shallow-water conditions imply, may have shut out the ocean waters during part of this period; this is rendered probable by the evidence of a movement at the close of the Permian said to exist in other regions. The erosion which took place at the close of the next succeeding movement is known to have been locally very great in the Rocky Mountains. Whether the marine Jura, as developed to the west and north, was deposited in this region and has in great measure been eroded away, or whether its elevation was such that the early Jurassic seas did not penetrate it, remains yet to be determined by future investigation. The only fact bearing upon this point is the observation by Mr. G. H. Eldridge of an unconformity by erosion between the Trias and fresh-water Jura along the foothills of the Colorado range near Denver.

LATE PALÆOZOIC LAND.

The outlines of the various land areas during the subsidence that followed this movement were, as far as can now be determined, somewhat as follows:

Colorado Island.—Along the eastern and northern shores of the Colorado island, no upper Carboniferous beds corresponding to the conglomerates of the Elk and Sangre de Cristo mountains have yet been recognized. The Triassic "Red Beds" now rest directly on an Archæan or lower Palæozoic basement, as the case may be. Hence it may be assumed that during upper Carboniferous time these shore-lines were still above water, and that the subsidence had continued into Triassic time, so that what upper Carboniferous sediments might have been deposited were overlapped and buried from sight by those of the Trias. Triassic sediments invaded the depression of North park, but apparently did not extend far into the Middle park.

South park was connected with the western ocean across the northern end of the Mosquito range, as in early Palæozoic time, and received a complete and regular series of sediments. On the south the bays at Manitou and Cañon City were probably not so deeply invaded as in early Palæozoic time, nor is there any evidence that upper Carboniferous or Triassic sediments ever oc-

cupied Webster park or Parkdale valley; if they did they have since been very completely eroded away.

Park range was probably isolated and formed an island, which was not connected with the Colorado island. Along its present shore-lines the upper Carboniferous beds are now so completely masked by subsequent Mesozoic sediments that their original extent cannot be determined. They are disclosed, however, by the more recent uplift and erosion of the White river plateau to the west, over which area sedimentation apparently went on continuously without leaving any very marked evidence of the movement.

Sawatch Island.—Around the immediate shores of the Sawatch island sedimentation apparently went on in unbroken continuity up to the time of the Jurassic movement, no evidence having yet been detected in the remarkably regular series of beds that now surround it of any dynamic disturbance. The character of these sediments shows, however, that shallow-water conditions prevailed from the middle of the Carboniferous to the close of the Trias, some small deposits of coal having been locally formed, and beds of coarse conglomerates, containing pebbles that must have been derived from some neighboring land-mass of Archæan rocks, constituting a very considerable proportion of the section exposed. Alternating with these are occasional beds of limestone, which are of so frequent occurrence and have so little persistence that they cannot be assumed to necessarily imply deep-water deposition, but rather local changes in conditions of sedimentation.

On the immediate western flanks of the Sawatch range, in the Elk mountains, were deposited at this time a thickness of not less than three thousand feet of reddish conglomerates, characterized by a great abundance of limestone pebbles associated with those of Archæan rocks, of which no lithological correspondents are found in the beds encircling the Sawatch uplift. These beds have been deposited over eroded surfaces of previously folded Palæozoic beds, and Carboniferous fossils have been found in some of the pebbles. Their material must have been derived, therefore, from the abrasion of some land-mass formed by the upheaval during this movement of an area over which sedimentation had been going on during early Palæozoic time. They could not have come from the erosion of the Sawatch island, otherwise the time correspondents of these beds around that island would have contained limestone pebbles also.

A careful consideration of the present stratigraphical conditions of the region shows that this land-mass must have existed somewhere to the south of the Elk mountains in the region about the head of the Gunnison valley, and possibly extended towards the northern end of the San Luis park. This land-mass may have been connected with the southwest end of the Sawatch island.

At the southeast end of this island is a similar unusual thickness of coarse

sandstones and conglomerates of prevailing red color, exposed by the erosion of the Arkansas river after it assumes its eastward course, which occupy a corresponding stratigraphical horizon, without, however, showing any evidence of unconformity with the beds below.

Wet Mountain Island.—The Sangre de Cristo mountains, from the Arkansas river southeastward to the head of Huerfano park, must have formed the western shore of the Wet Mountain island at this time, their relative positions as mountain and valley having been then the reverse of those which exist now. This range opposite Silver Cliff is largely made up of an immense thickness of conglomerate whose pebbles, of all varieties of Archæan rock, cannot have suffered any very prolonged attrition, for they not only consist of relatively soft material, but are sub-angular and often in immense blocks over 25 feet in diameter which could not have been carried very far.

It seems probable that these conglomerates extend the entire length of the range, since they have been observed by Stevenson on its eastern flanks, extending beyond the state line into New Mexico, where they contain limestone pebbles associated with those of Archæan rocks. He gives them an aggregate thickness at one point of about 6,000 feet.

It is a question whether the material of which they were composed was derived from the Wet Mountain island or from some land-mass to the westward which has now disappeared. The fact that on the east flanks of the Wet Mountain island no beds at all corresponding to them in thickness or coarseness of material have been found, would favor the latter conclusion.

The section at Cañon City shows a thin limestone conglomerate or breccia, made up of slightly rounded fragments, immediately and unconformably overlying the lower Palæozoic beds, and succeeded by a few hundred feet of beds mostly of reddish arkose material with a few limestone pebbles near the base. The characteristic red sandstones of the Trias have either been eroded away or are overlapped and concealed by the unconformable Jura-Dakota beds. Two exposures of Triassic beds are indicated on the Hayden map south of this point along the eastern flanks of the Wet Mountain range. Elsewhere they have been overlapped by the unconformable Jura-Dakota series. In like manner, south of Huerfano park, along the east front of the Sangre de Cristo range, the Jura-Dakota beds abut directly against Archæan or Carboniferous rocks, and no Triassic beds have been recognized, except near its southern extremity.

San Juan Island.—In the San Juan region, elevation and erosion is shown to have taken place by the fact that on its northern flanks a slight angular unconformity is observed between the lower Palæozoic series and the coarse grits, sandstones and shales that were deposited during the later Carboniferous. This discrepancy of angle was not observed on the southern slopes of the mountains along the Animas cañon, but of the areas represented there

on the Hayden map as Devonian and Carboniferous the lower part is known to be Silurian and the upper part Triassic. If the upper Carboniferous is not exposed it must have been overlapped, as on the eastern shores of the Colorado island, by the succeeding Triassic sediments.

In the wide area of the Uncompahgre plateau, to the west and northwest, Triassic beds are well developed, and the Carboniferous exposures represented as resting directly on the Archæan are considered by Dr. Peale to belong to the upper portion of this series. It would seem probable that these and the similarly outlying regions of the Zuñi plateau and the Naciniento mountains were island elevations in the early Palæozoic seas over which no sediments were deposited, and that after the late Palæozoic movement they were depressed below the sea level, since recorded observations seem to show that continuous sedimentation went on over them from Carboniferous into Mesozoic time.

Conclusions and Correlations.—Without a special examination of the region with this object in view, it is difficult to make any satisfactory conjectures as to whether the Carboniferous beds at a given locality belong to those deposited before or after this movement, or whether both are represented. From the present evidence it would appear that in the middle portion only of this region was the movement accompanied by any marked dynamic disturbances, and that elsewhere it was in the nature of a parallel transgression.

Again, while in the interior the aggregate thickness of the Palæozoic beds reaches from five to seven thousand feet, along the east flanks of the Colorado range, in the Laramie hills of Wyoming and the Black Hills of Dakota their exposures rarely show more than seven or eight hundred feet of beds. While it is certain that in the latter regions the lower Palæozoic beds are represented, no evidence has yet been presented to show that upper Carboniferous horizons are exposed there; but the Triassic "Red Beds" are in most cases characteristically developed. Palæontologically, Coal Measure forms, which are abundant throughout the Carboniferous beds, cannot be considered characteristic of either series, and it is only those having a Permian facies that afford definite evidence of the existence of the upper Carboniferous beds. On the other hand, in the Rocky Mountain region the lithological characteristics, that further west serve to distinguish the beds carrying a Permian fauna from the Carboniferous on the one hand and from the Trias on the other, are wanting; and there are very considerable thicknesses of beds about which it can only be said that they were deposited somewhere in the interval of time between the Carboniferous and Jurassic movements. Whatever may be predicated in regard to the orographical history of this interval is necessarily based upon data which are liable to be modified in the future, and hence are very conjectural. It is, that the elevation accompanying the movement was followed by an irregular subsidence, which was more pro-

nounced in the interior region, but in the outlying region was followed by further subsidence in Triassic time, as a result of which the earlier beds were overlapped to such an extent by the Triassic sandstones that they have rarely been exposed by later movements or erosion.

In the Wasatch and Uinta regions, the upper Carboniferous and Permian are undoubtedly represented. If I am right in considering that only the upper members of the Carboniferous are represented in the Uinta range, it would become probable that the erosion observed by Powell in the cañon of Green river on the beds underlying the Carboniferous was produced during the elevation that accompanied this movement.

With regard to the broader and more continental elevations, the fact that over the Palæozoic continent of Utah and Nevada, as well as over the great Appalachian continent, not only Mesozoic but also Permian beds are wanting, would indicate an alternate movement between those regions and the Rocky Mountains—that is, that during the Carboniferous elevation of the latter these still remained below the level of sedimentation, though shallow-water conditions prevailed to a certain extent, but that, while in the Rocky Mountain region subsidence continued into the Trias, the continents on either side reached a permanent elevation at the close of the Carboniferous time which was so far maintained that the waters of the ocean never again invaded them.

A similar condition, according to present evidence, would seem to have obtained in northern Mexico; for Dr. White* considers that south of the 34th parallel no Trias or Jura exists, but that the marine lower Cretaceous (which also includes possible representatives of the *Atlantosaurus* beds) rests directly upon the Carboniferous.

The Jurassic Movement.

The succeeding orographic movement of the region, which was even more widespread and more marked in its effects, has been designated the Jurassic movement, because the first beds deposited after it were those containing the vertebrate fauna determined by Professor Marsh to be of late Jurassic age, and called by him "*Atlantosaurus* beds." A somewhat meagre fresh-water molluscan fauna, considered by Dr. White as also of late Jurassic age, has been found by him in the *Atlantosaurus* beds of the eastern flanks of the mountains, and by Mr. Eldridge in beds corresponding stratigraphically and lithologically with these on the west flanks in the Elk mountain region, where the dynamical effects of the movement are most marked and have been most carefully studied. The beds which in the Rocky Mountain region are characterized by this fresh-water Jurassic fauna are generally very thin, contain as a rule but scanty remains of organic life, and want the persistence and

* Am. Journal Sci., 3d ser., Vol. XXXVIII, 1889, p. 440.

peculiar lithological composition of the overlying Dakota Cretaceous which renders that formation one of the most readily recognizable of all the Mesozoic series. As actual observation has shown that in some cases the earlier geologists included these beds in their Dakota formation, the term Jura-Dakota has been used in this paper to designate the beds first deposited after the movement, in order to distinguish them from the marine Jurassic beds of other regions, which were deposited before them; without, however, implying thereby, in localities that have not been personally observed, more than the probability of the existence of the fresh-water beds.

The evidence of this movement thus far obtained is of two kinds: First, that derived from personal observation in regions of violent disturbance, where, during the elevation produced by the movement, considerable areas had been uplifted by folding, often combined with faulting, and great thicknesses of rocks, sometimes thousands of feet, had been eroded away; and where, during the subsequent depression, Jura-Dakota beds had been deposited upon these eroded surfaces. The most marked evidences of such movements are found in the Elk mountain region, where, along a single line of strike, the Jura-Dakota beds upturned during the post-Cretaceous movement are seen to rest alternately and in repeated successions upon beds of all the horizons from Archæan up to Trias, and to rest upon the latter in the middle of the region in perfect conformity. Other violently disturbed regions observed are the northern Mosquito range, the eastern flanks of the mountains near Cañon City, and the northern portion of the San Juan mountains.

The second class of evidence is the fact indicated by geological maps that the Dakota Cretaceous, presumably Jura-Dakota, rests directly upon Archæan or Carboniferous at very many points throughout the region. In the other portions of the region, where the Jura-Dakota is represented as resting on the Trias, unconformity by erosion has in a few cases been detected.

The most persistent and readily recognizable horizon of Mesozoic age in the Rocky Mountains is the Dakota Cretaceous. It is prevailingly a sandstone with a characteristic basal conglomerate, the sandstone becoming readily quartzitic, even when adjoining sandstones are not altered, so that its upturned strata, owing to their resisting nature, always stand out prominently. The fresh-water Jura below it, so far as it has been studied, generally has a sandstone at or near its base which is softer and frequently cross-bedded to a remarkable degree. Between these two sandstones is a series of shales and clays, carrying a certain amount of limestone, which in some places forms a continuous bed, and at others occurs in lenticular bodies in the shales. The shales are frequently variegated in color, and beds of gypsum are sometimes found.

The Cretaceous beds above the Dakota consist, in the Fort Benton group, largely of dark shales, with a slight development of limestone, often bitumi-

nous; in the Niobrara, light-colored limestones predominate over the shaly members, becoming chalks in the deeper portions of the seas. The Fort Pierre is a great thickness of gray shales mostly argillaceous, while in the Fox Hills the shales become more arenaceous and pass into sandstones at the top of the formation. The Laramie is mainly sandstone in the enclosed sea-basins near large land-masses, with an increasing admixture of shales as the distance from these land-masses increases.

An abundant and characteristic verterbrate fauna has been discovered in the Jurassic beds at Como lake, in Wyoming, and at Cañon City and Morrison, in Colorado; a somewhat meager fresh-water molluscan fauna is associated with this in the two former localities, and some of the same forms occur at a corresponding horizon in the Elk mountains of Colorado. They are also reported from the Black Hills of Dakota and somewhat doubtfully from the Green River basin of Wyoming.

The Dakota formation carries an abundant flora which includes many deciduous plants, but in the Rocky Mountain region no marine forms have yet been found in it. The faunæ of the other horizons of the Cretaceous up to the Fox Hills are all marine, and in the Rocky Mountain region the change from the marine forms in this horizon to brackish-water forms in the Laramie is most marked and distinct.

JURASSIC LAND.

The more detailed and local effects of the Jurassic movement upon the various land areas under discussion were, so far as present facts afford any indication, somewhat as follows:

Colorado Island.—The general outline of Colorado island as determined in early Palæozoic time had thus far not been essentially changed. A general encroachment of the ocean upon its shores had been in progress, whose effects were more marked in the shallow bay-like depressions at its northern and southern extremities than along its steeper east and west shore-lines. The present areas of the North and Middle parks then formed a single depression, the present dividing line between them having been formed in post-Cretaceous times. North park had already been invaded by ocean sediments, and after the Jurassic movement further subsidence took place, so that the sea extended through the Middle park connecting with the waters occupying South park, and also across the Gore mountains westward to the Colorado plateau waters.

The relative distribution of the marine and fresh-water Jura is as yet but imperfectly known. To the west of the Laramie plains, throughout the Uinta and Wasatch regions and in eastern Idaho, the marine Jura is well developed, but as yet no fresh-water beds have been recognized; while at the Como lake anticlinal both marine and fresh-water Jura are found.

On the eastern shores of the Colorado island no evidence of the existence of marine Jura has been found south of the latitude of the Laramie plains. The fresh-water beds rest directly upon the Triassic without any apparent discrepancy of angle. The thickness of "Red Beds" assigned to the latter age varies very greatly from point to point. This would naturally be explained by the unequal erosion of these beds during their elevation; but where the evidence of sub-aerial erosion seems insufficient it might be partly accounted for in the case of beds, which like these bear internal evidence of having been deposited in strong along-shore currents, by the existence of broad, ridge-like corrugations in the sea bottom extending out at an angle to the shore-line, on the crests of which the accumulation of sediment would be much less than in the adjoining depressions. There is some evidence of the formation of such corrugations during the movement of elevation at various points along the eastern front of the mountains, though it cannot always be definitely assigned to this period.

In the Cañon city region there is evidence of considerable elevation and erosion during the movement, followed by a subsidence which admitted the Jura-Dakota waters to Webster park and to the valley of Parkdale at the west end of the Royal gorge. How far these waters extended to the northwest towards the South park depression has not yet been determined. Near Cañon City the discordance of strike between the now sharply upturned Jura-Dakota and the underlying beds is most marked, and points to a very considerable disturbance and erosion of the latter before the former were deposited. As the immediately underlying beds are here very soft and easily eroded, the actual contact and any discrepancy of dip-angle that may exist with these intermediate beds, whether Carboniferous or Triassic in age, has not been observed. The Jura-Dakota beds rest at different points, however, on these, on the early Palæozoic beds, or on the Archæan; and their discrepancy of angle with the two latter is very marked.

The western shore-line of the Colorado island is more difficult to define than the eastern, since it has been more extensively faulted and eroded in post-Mesozoic times.

It is noticeable that the northwest structural line along which the greatest disturbance has taken place passes thorugh the Cañon City region just described. The most notable effect of the orographic movement along this line was the cutting off of the previously existing connection between the South park bay and the western ocean of the Plateau region, an effect which has a more than local significance. It was produced by an uplift of the northern portion of the Mosquito range and of the Gore mountains on the east side of the Mosquito fault, which has been traced northward along the western crest of the Mosquito range and thence northwestward along the west flanks of the Gore mountains to within fifteen or twenty miles of the Grand

river. The character of this uplift was not the simple uptilting of a block of the earth's crust into a monocline, as has been shown to be the prevailing character of movement in the Plateau region by the geologists who have worked there, nor the vertical upthrust of a block bounded by two lines of faults, which one of them has propounded as the type of the uplift of the Park province or Rocky Mountain region. It was the result of compressive folding, producing a fracturing or faulting along the steeper side of a one-sided or S-fold, which is the prevailing structural type in this region. From the northern end of the Mosquito range and the Gore mountains, thus raised above the ocean level, the sedimentary beds from Cambrian up to Triassic, which had been deposited upon them around the northern end of the Sawatch uplift, were almost entirely eroded away, a few patches only remaining on the crest and steeper western side of the uplift to prove the character of the fold. Around the eastern and northern flanks of this uplift, from the waters which during the succeeding depression entered the Middle park, whether from the north through North park or from the west across the Park range north of the Gore mountains, the Jura-Dakota beds were deposited directly upon the denuded Archæan ; west of the Park range they stretched continuously across the fault line and rested in apparent conformity upon the Triassic beds, north of Eagle river and west of the fault line, which had escaped erosion.

This view of the structure of the region, which involves important modifications in the structural history of the Mosquito range given in my monograph upon the Leadville region, has naturally been adopted with extreme reluctance and under the influence of gradually accumulating evidence in its favor, combined with an inability to explain the known geological occurrences in any other way. In that monograph * I assumed, in the absence of any direct evidence of dynamic movements previous to the close of the Cretaceous, that the folding and faulting of the Mosquito range was probably post-Cretaceous, although I foresaw the possibility and even probability that further investigation might lead to a modification of this view. The age of the porphyries, which were folded and faulted with the enclosing sedimentary beds and hence were necessarily older than the dynamic movement, I assumed to be late Cretaceous, since similar rocks are found in other parts of the Rocky Mountains cutting through the latest Cretaceous formations.

According to my present view a part at least of the uplift of the Mosquito range must have occurred in Jurassic time, though I still think that the mountains were further disturbed and uplifted during the great post-Cretaceous movement. The greater part, if not all, of the porphyries must, however, have been intruded before the Jurassic movement, and the original

* 1886, pp. 23 and 31.

ore-deposition of the region must also be assigned to a period anterior to that movement.*

North of the Gore mountains, the Park range opposite Middle park was submerged, for a distance not yet determined, during the Jura-Dakota subsidence; but the northern part of the range remained above water, and the Grand Encampment mountains may, as already suggested, have formed part of the same island with the Medicine Bow range. Tertiary and Recent deposits now mask the flanks of these mountain masses to such an extent that all that can be said with certainty is that the Cretaceous deposits wrapped around them without apparently extending up the present valley of the North Platte as far as the North park.

Wet Mountain and Sangre de Cristo Islands.—During or possibly even before the Jurassic elevation, these two islands were consolidated into a single land-mass, which may now be called the Sangre de Cristo island. If any Triassic sediments had been deposited between them upon the upper Carboniferous they had been entirely eroded away. The eastern shore-line of this land-mass had the same general outline as the mountain front of to-day, with a reëntering bay at Huerfano park extending somewhat further into Wet Mountain valley than it does at present, and probably some submerged ridges making out at an angle from this shore-line. Either from unequal deposition over these ridges, as explained above, or on account of an unequal erosion of the Triassic beds, the latter are only found at widely separated intervals along the flanks of the Wet mountain range, and are apparently altogether wanting along the Sangre de Cristo range, except possibly at its southern end, in New Mexico. The Jura-Dakota beds consequently rest for the most part upon upper Carboniferous or Archæan rocks at different points along the shore line.

The western limits of the Sangre de Cristo island may never be accurately determined, for the reason that on this side the basement rocks are now completely concealed beneath the recent alluvial deposits of the San Luis valley and the immense flows of igneous rocks to the north and west of this depression. From observed conditions in the present known exposures of Mesozoic beds in this region, however, it seems probable that it formed a continuous land-mass with the San Juan uplift, and that the Jura-Dakota shore-line bent around the southern end of the present Sangre de Cristo

*I regret to say that a locality of critical importance with reference to this movement has not, so far as I can learn, ever been visited by any geologist now living. This is the northwest corner of the Gore mountains where the Mosquito fault, according to the indications of the Hayden Map, after separating the Triassic on the west from the Archæan on the east, is cut off at right angles by Jura-Dakota beds stretching across its path and resting on either formation. The geological outlines there given, however, were laid down by the hand of Mr. A. R. Marvine, who surveyed the region, but whose untimely death occurred before he had written up his field-notes for publication. Experience has given me such confidence in the accuracy of Mr. Marvine's work that I have no hesitation in accepting the essential correctness of these outlines, which are partially confirmed by the observations of Mr. Holmes, who crossed the fault a few miles south of this point, and by those of myself and my assistants, who have traced minutely the Mosquito fault northward to within twenty miles of this point.

range not far north of Santa Fé, and thence ran northwestward across the Rio Grande valley, westward around the head of the present basin of the San Juan river, and again northward across the west flanks of the San Juan mountains at the head of the Dolores and San Miguel rivers, turning eastward again across the heads of the Uncompahgre and other tributaries of the Gunnison.

It is possible that the northwestern extension of the Jurassic land-mass connected with the southern end of the Sawatch island, for all Mesozoic sediments are now wanting between the Arkansas and Gunnison rivers.

The San Juan area was, during the period of elevation, uplifted and eroded in such a manner that along the northwestern flanks the Jura-Dakota beds, which were deposited during the succeeding subsidence, not only rested in distinct angular unconformity upon the edges of the Triassic and upper Carboniferous beds, but overlapped in places onto the underlying lower Palæozoic series. On the southern flanks, however, the angular unconformity is not readily apparent, but the Triassic beds apparently thin out and finally disappear to the eastward of the Animas cañon, having probably been eroded away.

Sawatch Island.—The area of the Sawatch island was very largely increased during this movement, not only by the recession of the surrounding seas, but by the actual addition of adjoining areas by dynamic movements. That on its northern extremity has already been mentioned. The uplift of the northern portion of the Mosquito range and of the Gore mountains extended its area to the borders of the Middle park. A thickness of not less than 6,000 feet of beds has been eroded from the crest of the Mosquito range, and, although it cannot be assumed that this was entirely accomplished during the period of elevation, it is evident that enough time must have elapsed to allow of the complete denudation of the northeastern flanks of the Mosquito range where Jura-Dakota beds now rest directly upon the Archæan.

On the west side of the Sawatch there is more definite evidence of the amount of erosion that must have taken place after the upheaval that accompanied this movement. It is in the Elk mountains that this record is now found—a region that was so intensely disturbed in the post-Cretaceous movement that it is now impossible to correctly outline the land area that was added to the Sawatch island, or even to say with certainty that the portions of this region that must have been above water were actually connected with it. It is probable, however, that a ridge extended eastward from the region at the head of the valley of Roaring fork to Treasury mountain, and that another extended southward toward the ancient land-mass at the head of the Gunnison valley, from each of which the Triassic beds, and in some cases a large portion of the upper Carboniferous, were eroded. The best localities for studying the effects of this erosion and the unconformity of

the Jura-Dakota beds with those on which they rest are along the western flanks of the mountains in the present valleys of Slate and East rivers, which flow southeast, and of Rock creek, which flows northwest. Along these valleys the beds are now upturned at a sharp angle and often inverted, and it is by discrepancy in strike alone that the unconformity is shown. Proceeding northwestward from the Gunnison river up the former valleys, the Jura-Dakota beds are first found resting directly upon the Archæan; then on the east side of the valley, neglecting minor irregularities due to local folds and faults, they rest successively on upper Cambrian, Silurian, lower Carboniferous, upper Carboniferous, and, finally, at Copper creek, opposite the town of Gothic, near the head of East river, they rest in apparent angular conformity upon the Triassic "Red Beds." Following the strike further northwestward, the Jura-Dakota contact descends again in horizon, resting upon upper Carboniferous beds and, around the remarkable Archæan protrusion of Treasury mountain, upon lower Palæozoic limestones, now changed to most beautifully variegated marbles. Still further north along the valley of Rock creek, the upper Carboniferous and Trias come successively up to the base of the Jura-Dakota.

In the region along the Grand river and the White river plateau beyond it, which has not been visited by the writer, no unconformity between the Jura-Dakota and Trias is noted by the members of the Hayden survey, though the outlines on their maps are such as to suggest that evidence could be found both of this and of the earlier movement if they were studied to this end.

Western Region.—In the broad area south of the Gunnison and Grand rivers, which was a region of comparatively little disturbance in pre-Cretaceous time, no evidence of unconformity was noted by the members of the Hayden survey who visited it. The beds which they classed as lower Dakota in the coloring of their map are, however, the lithological correspondents of the *Atlantosaurus* beds as developed in the Elk mountain region; and Mr. Holmes has recently stated to me that he now considers them to belong below the Dakota and to be probably of Jurassic age.

On the eastern shore-line, at the base of the San Juan mountains, there is a heavy littoral conglomerate and an evident unconformity at the base of the Jura-Dakota, which has been noted also by Mr. R. C. Hills.* Whether the limestone, which he places below this unconformity and above the red sandstones containing vertebrate and plant remains of Triassic age, should be considered to represent the marine Jura of the Wasatch and Uinta mountains is somewhat uncertain, as no organic remains have yet been discovered in it.

Northern New Mexico.—Newberry and Holmes both failed to find any

* Am. Jour. Sci., 3d ser., Vol. XIX, June, 1880, p. 490.

Jurassic beds represented in northern New Mexico, although Marcou in his earlier explorations, coming to the region from the east and along a line not visited by either of the others, found beds corresponding to what he had considered as Jurassic in northern Texas. Newberry found Triassic plants in reddish sandstones immediately beneath sandstones which he regarded as Cretaceous, but it does not appear from his published accounts that their relative position was such as to preclude the possibility of a slight unconformity between them.

Further south, in the Zuñi mountains, Dutton found a considerable thickness of sandstones above the "Red Beds" which he regarded as probable representatives of the Jurassic of the Plateau region, although he obtained no fossils from them.

To the eastward, in the region around the southern end of the Sangre de Cristo range, Stevenson found the Dakota Cretaceous to have suddenly thickened to 1,700 feet from the normal development of about 300 feet which obtains with remarkable regularity from a few miles northward along the whole front of the Colorado range, and this thickening seems to have taken place below the sandstone generally recognized as characteristic of the Dakota throughout the Rocky Mountain region. He, also, failed to recognize the Jurassic of Marcou. Newberry, however, thinks to have recognized representatives of the fresh-water Jurassic in northern New Mexico *.

Texas and Arkansas.—Recent geological observations in Texas and western Arkansas show, according to Mr. R. T. Hill,† that the marine Cretaceous beds of that region have been deposited along the southern base of an uplift, as yet imperfectly known, of the Palæozoic rocks, extending from Arkansas westward through Indian Territory and northern Texas, and southwestward into New Mexico. It is not yet definitely known whether early Mesozoic beds are involved in this uplift, so that its formation could be correlated with the Jurassic movement in the Rocky Mountain region, though certain facts render this probable.

The Cretaceous beds are divided by Mr. Hill into an upper and lower series, divided by a land epoch marking a physical as well as a palæontological break. The upper beds deposited since this break show a similar cycle in the character of their sediments with the Cretaceous beds of the Rocky Mountains, with which they are correlated by Mr. Hill, the Lower Cross-Timber (Dakota) being a littoral formation, with basal conglomerate and abundant plant remains. The succeeding beds indicate gradually deepening waters culminating in the Rocky Comfort chalk (Niobrara), and showing evidence of a shallowing sea in the upper series, which corresponds to the

* Personal communication.
† Am. Jour. Sci., 3d ser., Vol. XXXVIII, 1889, p. 282.

Fox Hills—representatives of the Laramie not yet having been definitely recognized, possibly through having been eroded away.

Unconformably below these beds come a series of marine beds of lower Cretaceous age, known as the Comanche series, which have been traced through Texas southward into Mexico, the base of which is formed by the Trinity beds, or *Dinosaur* sands, which resemble the *Atlantosaurus* beds of the Rocky Mountain region. These rest unconformably upon the underlying beds, which in most cases thus far observed are found to be of Carboniferous age.

No representatives of the Comanche beds have yet been found in the Rocky Mountain region nor in the Plateau province; but from near the international boundary, in about longitude 115°, the Canadian geologists have traced a series of marine Cretaceous beds stretching northward into British Columbia, known as the Kootanie beds, which are lower than the Dakota Cretaceous. From the plant and molluscan remains found in these beds Mr. George M. Dawson * regards them as equivalents of the Comanche series (though perhaps not reaching quite as far back in geological time), and of those developed on the Pacific coast in Queen Charlotte's island, and considers that they were once connected with the latter north of the 54th parallel.

The Great Plains.—As early as 1877, Dr. White† called attention to the probability of a post-Jurassic subsidence which carried the eastern shore-line of the interior Mesozoic ocean eastward across the Great Plains and permitted the deposition of Dakota beds in central Iowa, which subsidence continued through Fort Benton and Niobrara times, causing a still further eastward extension of the shore-line and a corresponding change in the character of the sediments from shallow to deep water.

Since that time evidence has been found at various points throughout the area of elevation, folding and erosion of the underlying beds previous to this subsidence.

In the Raton mountains, some sixty miles east of Trinidad, Cretaceous beds rest unconformably on steeply upturned Triassic sandstones. North of this, at Fort Lyons, on the Arkansas river, an artesian boring disclosed a slight thickness of Jurassic beds interposed between the Trias and Cretaceous. Further east and north, through Kansas and Nebraska, the Dakota Cretaceous rests in places on Trias, at others on Permian or Carboniferous beds. The chalk beds, which in Texas correspond to the limestones of the Niobrara along the foot-hills of the mountains, have also been found in eastern Kansas, and recently in Nebraska as far west as the 103rd meridian.

General Conclusions.—The present distribution of Mesozoic sediments in

* Am. Jour. Sci., 3rd ser., Vol. XXXVIII, 1889, p. 120.
† Hayden's Report for 1877, p. 26.

the interior region of our continent shows that there were two principal meridional lines of depression in the earth's surface at that time, the one in the region of the Great Plains to the east of the Rocky Mountain front and the other to the east of the Wasatch uplift, each of which probably extended north beyond the Canadian boundary. The western continent beyond the Wasatch mountains had its greatest east and west extension between the 40th and 45th parallels of north latitude, the Mesozoic ocean extending further westward both to the north and south of this continent and possibly connecting beyond our boundaries with that on the Pacific slope. It is probable, therefore, that in these middle latitudes the general level of the country, as represented by its plains and valleys, was higher than in the more northern and southern regions, the bottoms of the principal depressions having a general slope northward and southward toward the present oceans.

The general elevation that accompanied the Jurassic movement therefore raised the whole interior region above the ocean, while the dynamic movements produced the effects already noticed within the Rocky Mountain region, and also raised a barrier which kept out the waters of the southern ocean, or Gulf of Mexico, from the eastern and partially, or possibly entirely, from the western meridional depression.

During the elevation a fresh-water lake, whose extent is as yet imperfectly defined, accumulated behind this barrier. It filled the valleys of the Rocky Mountain region and extended north as far as the Black Hills. It must have filled a portion at least of the Great Plains depression, but its western shore-line is now buried beneath Cretaceous deposits and may never be accurately defined. The extent of fresh-water Jurassic beds on the south and west of the Rocky Mountain region will, however, probably be determined in future examination of the region. At present it can only be said that fossils apparently belonging to this horizon are said to have been found in northern New Mexico by Newberry on the south, and on the banks of the Green river in Wyoming by Steward, of Powell's party, on the west.

During the gradual subsidence which followed this elevation the barrier was being eroded, and an outlet may have been formed through which the Jurassic lake was drained, so that no further deposition went on in its bed until it was again invaded by the ocean; though, as far as present evidence goes, the subsidence was not sufficient to admit the waters of the ocean within the Rocky Mountain region until Dakota times. Marine waters, however, must have entered the western depression from the north in British Columbia to admit the deposition of the Kootanie series of beds, and it seems not improbable that marine Cretaceous beds below the Dakota may yet be found in the western depression to the south, in the Plateau province.

That a certain amount of erosion of the fresh-water Jurassic beds after the drainage of the lake may have taken place in the Rocky Mountain

region seems probable from their apparent absence in certain sections and from actual proof of local movement and erosion discovered by Mr. Eldridge at Golden, Colorado; but it cannot yet be said that there was a general dynamic movement preceding Dakota time corresponding to that which Mr. Hill assumes to have affected the northern portion of Texas before the deposition of the upper Cretaceous there.

The character of the sediments and of the contained organic remains of the Dakota Cretaceous throughout the whole interior region, however, shows that they were deposited in a slowly advancing ocean during a progressive subsidence of the whole region. This subsidence continued to the middle of the later Cretaceous time, and was followed by an equally gradual elevation, which culminated in the shallow water conditions of Laramie time, when the oceanic waters finally retreated from the interior region even more slowly than they had advanced, never to penetrate it again.

The same general succession or cycle in the character of sediments deposited during later Cretaceous time may be observed throughout the interior region, though a variation is found in the thickness and in the prevalence of coarser or finer materials of the series as a whole, according as they were deposited near elevated land-masses and in narrow bays, or in broader seas at a distance from any considerable land-masses. While the sedimentation during this cycle was essentially conformable and undisturbed in character, a few unconformities by erosion have been observed, which indicate at least local movements about the middle of the period whose extent will probably be increased by future investigations. These are, an unconformity by erosion at the close of the Niobrara Cretaceous observed by G. Eldridge* at Golden, Colorado; one noted by F. B. Meek† at the same horizon on the Missouri; and a third at Austin, Texas, described by R. T. Hill‡.

The occurrence of lacustrine life in the Belly River and Dunvegan beds in Manitoba may likewise be found to be some way connected with these movements.

Correlations.—On the Atlantic border there is direct evidence of an orographic movement which seems to correspond pretty closely in geological time with that just described. The Triassic series of the eastern slopes, which include in places beds that are considered by some to be of Jurassic age, were uplifted, folded, and extensively eroded before the deposition of the succeeding Cretaceous beds. The earliest of the latter series, the Potomac formation, is essentially a shore-line deposit, and though its age is not fully agreed upon, some regarding it as late Jurassic and others as early Cretaceous, it may probably be considered to be the stratigraphical equivalent of the beds first deposited after the Jurassic movement in the Rocky Mountain region.

* Bull. Philosophical Soc. of Washington, Vol. XI, 1889 (in press).
† U. S. Geol. Surv. of the Territories, Vol. IX: Invertebrate Palæontology. Washington, 1876, p. XXXIII.
‡ Amer. Jour. Sci., 3d ser., Vol. XXXIV, 1887, p. 297.

On the Pacific border of the western or Nevada continent, both stratigraphical and palæontological conditions are much less easily defined. Whitney and King regarded the Jurassic beds of western Nevada, which apparently overlie conformably the Star Peak or Alpine Trias, as of the same age as the auriferous slates which are upturned against the western flanks of the Sierra Nevada, and considered the uplift of the Sierra Nevada as post-Jurassic and contemporaneous with that which folded the Nevada beds. As the Jurassic fauna of the latter corresponds with that of the marine Jura of the interior region, the movement would closely correspond with the Jurassic movement we are now considering.

Later observations by Mr. G. F. Becker* and Dr. C. A. White† differ in some respects from the conclusions drawn by Whitney and King. They consider the auriferous slates (Mariposa beds) to be palæontologically distinct from the Nevada Jurassic and to be more closely allied to the Knoxville beds of the Shasta group. Dr. White is not fully decided as to their age, but is inclined to place them in early Cretaceous (Neocomian) or late Jurassic. The Chico-Téjon beds, which rest unconformably upon the Shasta group, he considers as in part very latest Cretaceous (in this confirming Mr. King's earlier view) and in part early Eocene. While Mr. Becker does not commit himself definitely to a statement of the change in previous orographical views which this would involve, doubtless because he was on the eve of obtaining further and more decisive data from his proposed detailed study of the auriferous slates of California, he evidently foresees the necessity of some such view as the following, if future investigation confirms the conclusions then reached by Dr. White and himself. This is, that an uplift of the Sierra Nevada region occurred at the close of the Nevada Jurassic which permanently excluded the ocean from western Nevada and established the shoreline of the Mariposa beds and their contemporaries west of the crest of the Sierra Nevada, and that the movement which upturned these beds and produced the main uplift of the Sierra Nevada occurred in Cretaceous times previous to the deposition of the Chico-Téjon series and hence may prove to have been closely related to the great post-Laramie movement of the Rocky Mountain region.

It is an interesting coincidence that in Europe, also, there occurred an orographic movement in Jurassic time, in consequence of which, according to the generalizations of Suess‡ and Neumayr,§ the sea retreated entirely from the middle regions of Europe, where toward the close of this period only fresh-water sediments were deposited, and not until Cretaceous time did marine forms again appear.

* Bull. No. 19 U. S. Geol. Survey, Washington, 1885.
† Bull. No. 15 U. S. Geol. Survey, Washington, 1885.
‡ Antlitz der Erde. II Bd., Wien, 1888, p. 350.
§ Erdgeschichte. II Bd., Leipzig, 1887, p. 387.

The Post-Cretaceous Movement.

The post-Cretaceous movement, as has been almost universally recognized, was that which produced the main plication and faulting and played the most important part in determining the present orographic features of the Rocky Mountain region. But, as it is evident that these features had been in a great extent already outlined in the movements that went before, it is also more than probable that the post-Cretaceous folds and faults have been further emphasized along the principal lines of disturbance in the less violent movements that have affected the region since, even into very recent times. It is therefore manifestly impossible to determine with absolute accuracy how much of the present displacement of Cretaceous beds in folds and faults was produced in the first post-Cretaceous movement and how much in those that have supervened in Tertiary and Recent times. That during this movement the tangential thrust or force of compression was very intense is proved by the fact that in very disturbed regions the upper beds of a series, upturned against the flanks of an ancient island, often stand at steeper angle than the lower beds of the same series, producing thus something similar to the fan structure observed in the Swiss Alps.

The character of the sediments deposited during the periods immediately preceding this movement, which show gradually shallowing waters during the Fox Hills period, culminating during the Laramie in an entire change of its fauna through brackish-water into fresh-water forms, indicates a gradual elevation of the land until barriers similar to and perhaps more or less corresponding with those formed during the Jurassic movement cut off the whole interior region from the ocean. It might naturally be expected that during such elevation the shore-lines of succeeding stages would recede somewhat, and such Dr. White * states to have probably been the case with the eastern shore-line of the Cretaceous ocean in the Great Plains depression, which, he considers, after reaching its greatest extension during the Niobrara was carried westward during late Cretaceous times. In the Rocky Mountain region, where erosion and denudation have naturally been greater than in the plain regions, it is more difficult to determine the original extent of the beds last deposited previous to the orographic movement, since these were necessarily the first to suffer abrasion and denudation, which would have carried their outcrops further back from the original shore-line of the continental islands than those of the subjacent beds. Still, some idea of the probable extent of the Laramie deposits can be formed by considering to what extent they still occupy the great valley depressions formerly covered by the Cretaceous seas, since there denudation would have been less uniform and thorough than on the mountain slopes and ridges.

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* Hayden's Eleventh Report (for 1877), p. 260.

Laramie Land.—At the present time, within the mountain area roughly defined by the east flanks of the Colorado range on the east, by the Laramie plains, the Park range, White river plateau, and Elk and San Juan mountains on the west, and by the southern flanks of the San Juan and Sangre de Cristo ranges on the south, no beds of the Laramie or coal-bearing formation proper are known with certainty to exist, except in the South park. The beds which form the dividing ridge between the North and Middle parks, and which were colored on the Hayden maps by Marvine as of Laramie age, were so determined solely on the evidence of fossil plants, in spite of their unconformity with Cretaceous rocks below and their want of lithological correspondence with the Laramie beds developed elsewhere in Colorado. In North park Mr. Marvine discovered, in beds which he referred also to the Laramie group, though without expressing any opinion as to their stratigraphical equivalence with the Middle park beds, a few molluscs, of which Dr. White, after an examination of all the evidence both in field and office, says: "Of themselves they are not sufficient to determine the age of the strata containing them or their equivalency or otherwise with those of the Laramie group."* A recent examination of these Middle park beds made under my direction by one of my assistants has satisfied me that they were deposited after the post-Cretaceous movement, and that if Laramie beds proper were ever deposited in the Middle park they have since been removed by erosion. As in the adjoining South park Laramie beds still remain under very similar physical conditions, there seems to be some reason for assuming that the Laramie shore-line did not reach as far south in the Middle and North park depression as did that of the earlier Cretaceous seas in which case the bay in which the South park Laramie was deposited must have had its connection with the open sea by way of Cañon City.

In Huerfano park, which forms the southern end of the Wet Mountain valley depression, Laramie beds still underlie unconformably the Eocene Tertiary deposits which Mr. R. C. Hills has recently discovered there, but it is not probable that they ever extended much further north in this depression than the present divide.

No Cretaceous deposits whatever have been found in the depression of the San Luis valley, and if this depression, as I assume on confessedly rather indefinite grounds, was formed, like the valley of the upper Arkansas, by post-Cretaceous displacements and recent erosion, the Cretaceous seas did not cover it at all, except possibly the extreme southwestern border now buried beneath recent eruptive rocks.

On the western edge of the mountains, on the other hand, the great area of the Uncompahgre plateau and the valleys of the Gunnison and lower Grand river, from which the upper Cretaceous beds are now almost entirely

* Op. cit., p. 203.

absent, was probably to a great extent covered by the Laramie deposits, which may also have covered a great part of the present area of the Elk mountains and of the White river plateau.

On this method of reasoning, therefore, it would appear that already in Laramie time the ocean waters had in great measure receded from the interior portion of the Rocky Mountain region which they had occupied in the earlier part of the Cretaceous period, but that this recession was accompanied by no dynamic movements. These movements were initiated only after the coal-bearing Laramie beds had been deposited, and whatever sediments were formed in the region after these movements were laid down in lacustrine waters.

Date of the Movement.—I have spoken of this movement as post-Cretaceous, although, as occurring at the last stage of that series, it might more strictly be called post-Laramie. Twenty years ago the former term might have been objected to as fixing too early a date for the movement; to-day there seems to be some danger of a similar objection being made to it on the ground that it implies too late a date. All geologists are more or less familiar with the controversy which existed so long as to the age of this important formation, which carries almost all the economically valuable coal deposits of the Rocky Mountain region. It arose mainly from the fact that in the earlier explorations fossils were brought in from widely separated districts whose stratigraphy under the circumstances could not be exhaustively studied; hence correlations had necessarily to be made on palæontological evidence without that accurate knowledge of the stratigraphical succession and structural relations of the beds in question which is an indispensable basis for the correct determination of horizons in a new geological field. The determinations made by various classes of specialists under these conditions presented a wide range for the same series of beds. By the vertebrate palæontologists the Laramie was considered without doubt of Cretaceous age. From a study of its molluscan remains opinions varied between Cretaceous and Tertiary, with a decided leaning toward the latter; while the palæobotanists assigned some of its beds to the Miocene and others to the upper Eocene, the former being in actual stratigraphical position nearest the base of the series.

The geologists of the Fortieth Parallel, who first introduced in the western mountain region systematic examinations of continuous areas based on topographic maps of these areas, after following Laramie outcrops in a belt one hundred miles wide across eight degrees of longitude, found that statigraphically and structurally it belongs to the Cretaceous, forming the closing phase of a continuous sedimentation through that period, and being followed by the most marked physical break since that at the close of the Archæan.

Professor L. F. Ward*, in his historical review of the opinions held in regard to the Laramie group, seems to regard the point of view assumed by Mr. King in summarizing the evidence on this subject as puerile; nevertheless I am convinced that much of the confusion that has obtained in the minds of palæontologists in regard to the proper position of these beds in the geological column would have been avoided had they possessed an accurate knowledge of the stratigraphical relations of the beds of each locality from which their fossil evidence was obtained.

No one has done more to reconcile the opposing views and clear up this confusion than Dr. C. A. White, who has combined in his work the qualities of the structural geologist with those of the palæontologist. In his recent review of the North American Mesozoic † he says:

> "The formations which overlie the Laramie were, by common consent, long ago regarded as of Tertiary age; but concerning the age of some of them, differences of opinion have since arisen. Between the Laramie and any overlying formation there is often, but not always, unconformity. In Utah, and apparently in the valley of the Yellowstone also, I have found the Laramie passing gradually up into purely fresh-water deposits without any stratigraphical break. In the former case I am sure, and in the latter case I believe with Professor Newberry, that the upper strata represent the lower part of the Wasatch group."

Without knowing more about the locality referred to than is here expressed, I should not consider, from a stratigraphical standpoint, that this disproved in any degree the unconformity, and the orographic movement which that implies, between the Laramie and the Wasatch; since in the broader depressions away from the immediate vicinity of a line of disturbance the succeeding beds, even after a physical break, may be expected to be found quite conformable with those below them. As regards continuance or non-continuance of certain forms of life across such a break, I do not wish to invade the province of the biologist in offering an opinion, but would merely suggest that the probable persistence of land areas of some kind throughout the various orographic changes that have occurred in this region, which I have here insisted on, would seem to be of some importance in explaining survivals here which are unusual in other regions.

As regards the coal-bearing Laramie in the Rocky Mountain region, which I have hitherto spoken of as the Laramie proper, it has now been examined more thoroughly than any other formation on account of its economic importance, and those who have carefully studied it in one locality find no difficulty in recognizing it in others, in spite of local variations in character of sediment and thickness of beds. Its exact relation to the beds which have been deposited upon it since the movement in question are, however,

* Synopsis of the Laramie Flora: Sixth Ann. Rep. Director U. S. Geol. Survey, Washington, 1886.
† Proc. A. A. A. S., Vol. XXXVIII, Aug., 1889.

often obscure in a given section, and can only be accurately determined by a careful stratigraphical study of a considerable area. This is well illustrated in the case of the Denver region, of which a most exact and detailed survey has been made recently under my supervision by Messrs. Cross and Eldridge. They have shown that, since the movement at the close of the Laramie proper, there have been deposited upon its eroded surface two succeeding series of beds, of a thickness of 800 and 1,400 feet respectively, called the Arapahoe and Denver formations, the former of which was uplifted and eroded before the deposition of the latter. The great length of time that must have elapsed subsequent to the post-Cretaceous movement is proved by the fact that the Arapahoe formation is made up of material recognizable as derived from different horizons of the 14,000 odd feet of Mesozoic beds upturned by it, including the Laramie. It is further emphasized by the composition of the beds of the Denver formation, which are largely, and in their lower portion almost exclusively, made up of débris of a very great variety of andesitic rocks, none of which could be found in the lower beds and the source of which has not yet been discovered in the adjoining regions, showing that the interval must have been of sufficient length to admit of the outpouring of a great variety of andesitic rocks and of their almost complete denudation before the close of the Denver period.

In earlier examinations of the region, on account of the peculiarly complicated structural conditions, all these beds had been assumed to belong to one conformable series, and the plants collected from the Laramie beds and from the Denver beds above are indiscriminately designated by Professor Ward, in his Synopsis, as "from the Laramie at Golden," although I had previously called his attention to our discovery of the unconformity, and pointed out the differences in the matrices of the respective specimens in his collections.

With regard to the age which would properly be assigned to these later beds from a palæontological point of view—that is, as determined by the general laws of succession of animal and plant life, which the present knowledge of the development of life in Mesozoic and Tertiary times in other parts of the world have led biologists to make,—there exists considerable uncertainty. Of the organic remains thus far discovered neither plants nor invertebrates can be considered of sufficient taxonomic value to afford decisive evidence as to their Cretaceous or Tertiary age. The vertebrate remains, on the other hand, present the nearest analogy to a recently described vertebrate fauna, assigned by its discoverer to the Laramie Cretaceous. No published evidence exists of the stratigraphical or structural relations of the beds in which these occur; only the bare statement of the author that they belong to the Laramie. Furthermore, it is known that some of the beds, whose fauna is said by palæontologists to have a Laramie facies, are dis-

tinctly fresh-water and separated from the Laramie proper, or, as they designate it, "the lower Laramie," by a physical break; and this I have reason to believe is the case in at least one locality where the vertebrate fauna, which that of the Denver beds most resembles, has beenfound.

Conclusions—In no region can the palæontologist afford to neglect the evidence of stratigraphy and geological structure, and this is especially true in a new and extremely complicated region like the Rocky Mountains, where already the succession of life has been found in certain horizons to vary quite markedly from the laws previously established by studies in Europe and the east. The stratigrapher, on the other hand, must necessarily depend on the palæontologist for such determinations of the relative age of his horizons as will enable him to establish correlations between different series of beds between which there may exist stratigraphical or geographical gaps or hiatuses.

For the accumulation of material essential for true and complete geological history of a given region it is therefore necessary, not only that each should freely furnish the other with all the facts he has determined from his particular standpoint, but also that he should draw his conclusions, not from that standpoint alone, but give due weight as well to the evidence afforded from the standpoint of his collaborator.

It is in pursuance of this idea that I have laid stress upon the importance of the movement at the close of the coal-bearing Laramie in the Rocky Mountain region; and I desire to protest against what seems to be a tendency among those who are studying the palæontology of the region to give little weight to it, or even to neglect it altogether in their determination of horizons. It is unquestionably one of the most important events in the orographical history of the entire Cordilleran system. With the exception of the great unconformity between the Archæan and all overlying sediments, which is a phenomenon *sui generis* and altogether exceptional, no movement has left such definite evidence as that which followed the deposition of the coal-bearing rocks, to which the name Laramie has by universal consent been applied. Against the positive testimony of nearly horizontal beds of Eocene or later age actually overlapping the edges of more or less steeply upturned Laramie beds, found in so many and in so widely separated portions of the region, the negative evidence of conformity of angle between these beds in other localities has absolutely no weight at all.

It is further a fact universally admitted that while the beds deposited previous to the Laramie were marine, all deposited since that period were essentially fresh-water sediments. Now, it is known that land and fresh-water molluscs are of little value as indices of the passage of geological time. It seems reasonable, moreover, to assume that, in a region where land surfaces have existed throughout the orographic movements, fewer extinctions or

changes in plant life would be produced in the progress of geological time than where such movements produced an entire submergence of adjoining land areas. Hence it is to the successive changes in vertebrate life that we must look for the most definite palæontological evidence of the lapse of geological time.

Palæontologists tell us that, between the vertebrate fauna of the lowest Eocene beds yet studied in this region and that of the Laramie, there is an important gap in the normal succession of life that remains to be filled. It is now over fifteen years since Mr. King stated from the evidence then available that no Eocene beds existed on the eastern flanks of the Rocky Mountains, and this statement has held good until within the last year, when an extensive series of beds, over 7,000 feet thick, discovered by Mr. R. C. Hills at Huerfano park, on the eastern flanks of the range, have been determined to be in part of Eocene age, though they have not yet been sufficiently studied to determine their entire vertical range in the geological column. These beds overlap the upturned edge of the Laramie beds, as do, or did before removal by erosion, the Arapahoe and Denver beds already alluded to. It is probable that, as special investigations to this end are made, other series of beds, occupying an intermediate position between the lowest Eocene now known in the region and the coal-bearing Laramie, will be discovered; and it may be hoped that in time the gaps in the succession of life may be filled. From the nature of things it will probably be a long time 'ere such a complete knowledge of the succession of fauna can be obtained. These later beds were of limited and local extent, they have been but imperfectly consolidated since their deposition, and, being the first to be affected by. Tertiary erosion, they exist now only in fragmentary patches; hence it requires such minute and detailed study to determine their true stratigraphical relations as in the present stage of geological investigation in this country can seldom be accorded to them. Hence all determinations of succession of life based on palæontological evidence alone, must for a long time be provisory. It would seem, therefore, to be illogical, when there is an apparent conflict between the definitely determined physical evidence of an orographic movement and that afforded by analogy with the laws of succession established in other parts of the world, to allow the former to be neglected or even to be outweighed in making such provisory determinations.

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ON GLACIAL PHENOMENA IN CANADA.

BY ROBERT BELL, B. A. SC., M. D., LL. D., ASSISTANT DIRECTOR OF THE GEOLOGICAL SURVEY OF CANADA.

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CONTENTS.

Introductory Note.—In the following paper, Canada means more than the narrow strip along the eastern part of the northern border of the United States, with which the name was once familiarly associated in the minds of the citizens of the latter country. Leaving out Alaska, Canada now means the northern half of this continent.

The extent of the area in the northern hemisphere which has undergone glaciation during the drift period has now been pretty well ascertained, and the greater part of it proves to lie within the Dominion of Canada. Considering this fact and also the diversity in topography and climate presented by a country which stretches from the temperate zone to the north pole, it must be admitted that we Canadians have a splendid field for the study of the ancient glacial phenomena.

In 1863 the writer prepared the chapter on surface geology in the "Geology of Canada;" and ever since that time he has paid particular attention to this subject. His opportunities for personal observation in all

sections of the country east of the Rocky Mountains have been unequalled by any other single traveller, and it is therefore hoped that some points of interest will be brought out in the following paper.

The Evidence concerning Repetition of Cold Epochs.—Have we had in North America two or more distinct glacial periods, separated from one another by long intervals of time? This is one of the first questions which arise when we begin to classify our facts and describe the observed phenomena. Limited deposits of lignite occur between layers of till, especially in the more southern and western parts of the drift region, where the ice-sheet was liable to advance and retreat according as the conditions were more or less favorable for the accumulation of ice during cycles of years. I have found similar deposits as far north as the southern part of Hudson's Bay. But these facts seem merely to indicate temporary and local interruptions of the glacial condition, and do not afford proof of an interglacial period extending throughout North America and lasting long enough to require us to consider that there were two or more glacial periods wholly separated from one another. On the contrary, it appears as if all the phenomena might be referred to one general glacial period, which was long continued and consequently accompanied by varying conditions of temperature, regional oscillations of the surface, and changes in the distribution of sea and land and in the currents in the ocean. These changes would necessarily give rise to local variations in the climate, and might permit of vegetation for a time in regions which need not have been far removed from extensive glaciers.

Geographic Changes of the Pleistocene.—Geological explorations have now been made in all parts of the Dominion sufficient to show that the glaciation of the surface east of the Rocky Mountains has been universal, except in the northern part of the eastern Labrador range and perhaps in some of the higher parts of Baffinland. It is doubtful also if the Gaspé peninsula has been glaciated, except locally. What was the condition of the now glaciated area before the commencement of the drift period?

The relative contours of adjacent districts were probably something like what they are to-day, but regional elevation and depression have made great differences in the distribution of land and water on a grand scale. These changes of level, going on during the progress of the ice age, made great alterations in the distribution of the ice-sheets and in the movements of these wide-spread glaciers themselves, as proved by the various courses of the ice-grooves and the different directions in which the drift materials have been transported. The latter, after having been moved in one direction, have in some cases been partly carried off in another, owing to a change in the course of the ice movement. These changes of movement may have been brought about by an increase or diminution in the slope of the land or the relative elevations of different districts, but probably also largely on account

of altered conditions affecting the influence of the sea in one direction or another. For example, a comparatively small depression might establish a wide channel connecting two oceans. Such a thing might be conceived as taking place between waters covering the valley of the Mississippi and Mackenzie rivers. This would at once have an immense effect on the glaciers, which we may suppose to have existed on both the Laurentian and the Rocky Mountain sides of such a great strait.

Changes in the proximity of the open sea in the valley of the St. Lawrence and elsewhere may help us to account for the different directions followed by the ice-grooves and by the drift materials in these regions, as well as the changes in the elevations or slope of the land, which such alterations in the distribution of land and water would imply. That such changes have taken place appears to be pretty well established. Among other proofs of this is the fact that marine shells are found in the Pleistocene deposits along the St. Lawrence only as far west as Brockville, about 200 feet above the sea, where they have assumed the brackish water forms; whereas on Montreal mountain they occur up to an elevation of 500 feet, which is sufficient to have carried the sea all over the basin of Lake Ontario had the relative levels of the land remained the same as at the present time.

The Ante-Pleistocene Surface.—What was the condition of the surface of the northern part of the continent just before the commencement of the glacial period? There is every reason to believe that the Archean rocks, which occupy so large a portion of the glaciated area, had become deeply decayed and softened like those of the southern States, Brazil and Ecuador, at the present day. This softened crust would be easily ground up and swept away by the ice-sheet to form the deep and extensive layers of till which cover such large tracts in the more southern regions of Canada and extend into the United States. These layers have an average depth of perhaps 100 feet all over the extensive Paleozoic districts west and south of Hudson's and James's bays and in those of the province of Ontario, and the average depth may amount to 200 feet in Manitoba and a great part of the Northwest Territories. This till is largely mixed with the débris of the local Paleozoic or Mesozoic rocks, but so vast an amount of loose material could not have been produced by the glaciers working on a surface originally as hard and bare as that of the Archean rocks at the present time.

The rounded bowlders are probably to a great extent the remains of the hard nuclei or kernels, which, for some reason, in the case of crystalline rocks, remain unaffected in the decay of the surrounding mass, although a certain proportion of them, as well as nearly all the angular and sub-angular bowlders and the pebbles, have resulted from the breaking and shattering of the rocks along cliffs or about peaks and from the peeling up of beds beneath the glaciers.

The general outline of the great Archean area of the northeastern part of the continent and Greenland approaches an elliptical form, but its superficial continuity is broken in places by shallow water or thin basins of Paleozoic rocks. The whole area (excluding Greenland) has only a moderate elevation above the sea; and, on the large scale, it may be considered as nearly level, being interrupted only in a few parts by heights which can be called mountains. Yet every part of it which is not buried under the drift is broken up into isolated rounded hummocks, a condition which is best described as mammillated. The whole vast country has been planed down so thoroughly and deeply that few traces of the preglacial surface remain. The northern part of the coast range of eastern Labrador, probably the highest ridge in Canada east of the Rocky Mountains, has not been glaciated except locally in the valleys. It consists of Laurentian gneiss, like the rest of Labrador, but without a close examination one would not recognize in the peaks, serrated ridges, and earthy looking slopes of these mountains the same rocks that constitute the bare, hard, flattened domes of the Laurentides elsewhere. This range was probably much more elevated during the ice age and formed the starting point of the glaciers, which flowed northward into Ungava bay and westward into Hudson's bay. From the latter their course was still westward and southwestward to the western border of the Archean region and far beyond it in the Saskatchewan and Mackenzie river basins.

In the Gaspé peninsula, too, there appears to be an absence of travelled bowlders, if not of general glaciation, as was pointed out by the writer in 1859. In most parts of the region affected by the drift the only fragments of the preglacial surface so far discovered consist of limited beds of lignite and traces of the channels of rivers cut in the solid rocks, which are usually buried beneath the till.

In the valley of the Athabasca river towards the periphery of the glaciated region, where the ice-sheet was probably much thinner than over the Laurentian area to the east of it, the valleys bear evidence of preglacial origin. Some facts in this connection are given in the Geological Survey report by the writer for 1882. The depth and grandeur of the valley of the little Clearwater river have been remarked by all travellers in these parts. This stream flows westward and joins the Athabasca about 150 miles south of Athabasca lake. Above the junction the bed and valley of the main river are only large enough to accommodate the present stream, but below it the valley immediately becomes about a mile wide, with a level, wooded intervale between the banks, while the present river has a width of only one or two hundred yards. The Clearwater has steep banks from 500 to 600 feet high, with a width of about a mile between their brinks. In my report for 1882, I stated that "the valleys of both the Athabasca and Clearwater, as far as they are excavated in the Cretaceous and Devonian strata, may be

of preglacial origin. There appears to be no evidence that these rivers themselves removed so large an amount of rock; and drift materials, similar to those of the higher levels, are deposited equally below the more ancient walls."* The channels of the Clearwater and of the lower part of the Athabasca evidently form a continuous valley of large size, through which a greater river flowed for ages before the glacial period. The direction of the current of this stream would depend upon the slope of the country at the time. There is said to be a continuous water-course between the head of Clearwater river and Clearwater lake, connecting again with Isle á la Crosse lake, out of which the Churchill river flows. A slight elevation to the eastward would send the waters of the upper Churchill and all the drainage of the Isle á la Crosse basin down the Clearwater river, while on the other hand a greater elevation to the westward would turn the waters of Lake Athabasca and Peace river into the Churchill.

In the lower part of the Churchill river I found, in 1879, ancient gravel-filled valleys, excavated in solid limestone, and all covered over with bowlder-clay. Similar evidence of preglacial erosion was noticed in limestone in the lower part of Nelson river. On the Missinaibi river (southwest of James's Bay) I discovered several beds of lignite with till both above and below them. Another bed of lignite, three feet thick, which I have described on Coal brook, a channel of this river, rests upon blue and light colored clays and is overlain by about seventy feet of till. Traces of lignite, of the age of the drift, were also met with on Albany and Abittibi rivers. In one place the Kenogami river, which discharges Long lake into the Albany, cuts across an ancient valley, excavated in Silurian strata with a bed of lignite in the bottom and filled with drift materials, which also overspread the surface of the older rocks on either side of the preglacial channel. Lignite occurs beneath the drift on Rainy river and on the western side of the main body of Lake of the Woods. The lignite, or buried peat, of the south shore of Lake Superior and that of the Goulais river, on its east side, are overlain by modified sand and clay of more recent date than the till. But evidence of this kind is comparatively rare. It is seldom that anything is found between the till and the glaciated surface of the fundamental rocks.

The Evidence of Glacial Action.—With the exceptions already noted, the whole surface of the Dominion from the boundary of the United States northward to Baffinland has been thoroughly ice-swept. In spite of the mammillated aspect of the vast Archean region, the evidence of this great planing and denuding force is everywhere manifest. Its appearance on the grand scale may be compared to that of a hummocky surface of plastic clay which had been stroked by the hand. The valleys and the sides and tops

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*Geol. Survey Report for 1882, page 30cc.

of the hills have been alike rounded and smoothed—no place seems to have escaped. The proofs are innumerable that the denuding agency could have been nothing but land ice acting as a semi-fluid. There is no evidence that ice-bergs or other forms of floating ice had anything to do with the erosion. The general contours of the surface slope in various directions and the differences in level are very considerable, so that if this had once been the bottom of the sea there would be corresponding differences in depth.

It should be remembered by those whose imagination pictures ice-bergs performing the work of glaciers that, as a matter of fact, when a berg takes the bottom it stops entirely and often remains for years stranded at the same spot. The ice-grooves and furrows on the surface of the rocks constantly show that the yielding force, while producing them, must have been slowly forced round projecting knobs, through crooked channels of varying width, up hill and down dale, the upward slope being often very steep indeed ; that perpendicular walls and even the under sides of overhanging rocks are frequently grooved horizontally; and, altogether, that this force must have acted in a manner quite impossible for ice-bergs. To those who have seem much of the glacial phenomena in Canada, it seems incomprehensible that any man calling himself a geologist could believe these phenomena to have been produced by ice-bergs, provided he had had opportunities of observing at all. Such totally unsupported views could only be held on the "authority" of some of the older geologists who paid more attention to theory than observation, and who happened to jump to the conclusion that the ice-grooves and furrows had been produced by the rubbing of bergs on the bottom of the ocean, and that the transported bowlders had been dropped from such bergs as they passed along. This latter notion may be equally fallacious with the first, for the ice-bergs of modern times, at any rate, transport very little earthy or rocky material. Field or floe ice is a more important transporting agent, but it is the finer materials, such as mud, sand, and gravel, which are carried by this means.

It is probable that not only were vast quantities of loose materials, derived from the decayed surface, pushed forward under and in front of the ice-sheets of the drift period, but that a large amount of similar débris was incorporated in the substance of the ice itself. The latter would have a much more powerful effect in abrading the rocky surface than materials which were free to move and seek shelter wherever the pressure was least. Two points which have sometimes been overlooked require consideration in this connection: *First*, the effect of the temperature of the ice itself, because, of course, ice is capable of any temperature from that of the melting point down to the lowest possible degree; and *second*, the hydrostatic pressure of the great superincumbent mass upon the lower layers, for ice on the large scale would obey the same laws as a fluid. Those who have noticed the slight effect of modern

glaciers in forcing along bowlders or in producing striation of the underlying rock-surface should remember that their observations were confined to the melting extremities of glaciers when the temperature of the ice was at its highest possible point and when the hydrostatic pressure had almost vanished. The latter circumstance enables the ice to gradually rise and ride over the till, while the softened and comparatively warm ice, on the point of melting, would offer the least resistance to bowlders or any other solid objects. It should be further remembered that when these objects have become exposed so as to be visible to the eye they must constantly absorb heat from the air in summer and thus, as it were, thaw their way into the glacier as fast as it advances towards them, producing grooves in its substance just as a stone will sink into ice by gravitation. If, on the contrary, bowlders and finer débris be incorporated in very cold and hard ice thousands of feet beneath its surface and firmly held in their places by the enormous pressure from all sides, there can be no doubt of their acting as most powerful abrading agents. In places where the ice-sheet was from one to two miles in thickness, as some geologists reasonably enough believe it to have been, its weight would exercise not only an abrading but a tremendous crushing and bruising effect on the surface of the rock beneath. At times this would slightly displace great sections of rock exposed to its force and gradually break them up and wear them into bowlders, some of which might still remain of large size at the close of the drift period; or if the whole mass should happen to settle into a protected situation, or if the ice should disappear before breaking it up, the greater part of the mass might remain till the present day. The crevices or spaces between the rock *in situ* and the displaced mass would become packed with drift material, and the fact that the displacement had occurred at all could only be discovered in the side of a cliff, or by landslides or artificial cuttings.

A case of this kind appears to have occurred at Wine harbor, Nova Scotia, where a part of the area mined for gold seems to have been slightly displaced *en bloc*, as a layer of hard gravel and mud was found separating the upper hundred feet or so of rock from that below. In the cuttings along the Canadian Pacific railway, north of lakes Huron and Superior, seams or crevices filled with till are occasionally seen in the apparently solid crystalline rocks. When building the line at Rossport, on Lake Superior, a part of the mountain side including many thousands of cubic yards, slid bodily into the lake in consequence of one of these openings. It is probable that these crevices often act as reservoirs of water which feed the springs among the Archean rocks.

When we think of the enormous weight of the ice-sheet with its abrading materials beneath it, the only wonder appears to be that the evidence of its crushing and gouging effects is not greater than we see. These forces are

most conspicuously manifested where the more even course of the glacier has been interrupted by a rise or turn, or by some hard knob of rock in its bed. The immense pressure and the friction of the rocky débris would generate a certain amount of heat, and the ice, where very thick and mingled with earthy matter, would tend to retard the radiation of heat from Mother Earth; for, notwithstanding the fact that transparent ice is a conductor of heat, a mixture of ice and drift material a mile or two in thickness would retain terrestrial heat, although in a less degree than an equal depth of ordinary rock. The water thus produced would often be temporarily imprisoned and in the course of the movements of the ice would become subjected to great hydrostatic pressure, causing it to force passages for itself among the débris. This might account for some of the singular forms assumed by the drift materials.

The Direction of Glacial Flow.—The courses of the glacial striæ having been noted in all parts of the northern States and the southern parts of Canada before we knew much about them in the more northern region, it was assumed that the general direction was everywhere southward, with local variations to the east and west of south. This circumstance, along with the stupendous force which it was obvious must have produced the phenomena of continental glaciation, gave rise to the theory of a universal ice-sheet covering the northern regions of this hemisphere during the drift period. Our observations throughout "the great north land" have, however, modified this view, and it now appears as if something less would account for the wonderful facts of the great ice age in North America, as well as in the Old World.

The dispersion of the ice does not appear to have been from a single district in northern Canada, as supposed by some, but from several. One of these, as already stated, was in eastern Labrador; another lay between Hudson's bay and the Mackenzie river; while the wide, shallow basin of Hudson's bay itself formed the grandest névé and collecting ground of all. Besides the ice which formed directly from the copious snows falling on this vast expanse itself, continuous contributions were received from the Labrador peninsula to the east and the great region to the northwest, and the mass discharged itself northward into the deep and wide valley of Hudson's strait and southward and southwestward over the Paleozoic and Laurentian plateau. The ice-sheet appears to have flowed outward everywhere from the eastern, southern, and western margins of the great Laurentian plateau—that is to say, its general course was eastward on the coast of the North Atlantic, southward from the Strait of Belle Isle along the St. Lawrence and the Great Lakes to the Winnipeg basin, and southwestward and westward from thence to the Mackenzie river. A faint indication that the regions east and west of Hudson's bay, above referred to, were former centres of glacial

dispersion remains to the present day in the fact that the general isothermal lines appear to circle round them as the areas of greatest cold. As the ice-sheet increased or diminished there would, no doubt, be great local variations, and immediately to the south of the general Laurentian outline there was at one period a strong movement to the southwest up the St. Lawrence, from near Montreal, through the basins of Lakes Erie and Ontario and over the peninsula between the latter and Lake Huron. A similar movement took place from Lake Superior westward, carrying the débris of the red rocks of the Nipigon formation up over the Laurentian plateau towards the valley of Red river, as pointed out by the writer many years ago.

I do not like to offer any explanation of the above general facts; but it would appear that they indicate a greater elevation of the land than at present exists in the north and east. In addition to the aid afforded by gravitation, the movement of the ice was probably largely due to its continual accumulation in certain regions and its constant thaw in others, the latter being due not only to the heat of the sun but also to the influence of the warm water of the ocean in the direction towards which the ice traveled. A further cause of the southward tendency of the ice, which I have not seen referred to by other writers, would be the tangential component of the centrifugal force due to the rotation of the earth on its axis.

The Archean country is thoroughly denuded of everything down to the bare rock. The eroding force must have been most powerful and long continued. As a rule, not only is all the decayed rock gone, but even the crushed or loosened portions, leaving a smooth and sometimes polished surface, well calculated to resist the denuding agencies of the present period. The general form of the rocky domes which remain has been shaped by the same force. The longer diameter of each, as a rule, is parallel to the direction of the striation of the locality and the stoss or crag end is steeper than the tail or lee extremity. The rock of the stoss side, which had been long exposed to the stream of ice, like the upper side of a pier in a river, is more solid and free from joints and flaws than that of the tail, showing deeper erosion. In confirmation of this, it was found in constructing the Canadian Pacific railway north and west of Lake Superior that it was more difficult to remove rock on northward than southward slopes. The general bearing of the striæ gives us the line of the ice movement; but it is not always safe to assume that it came from the side indicated by any preconceived theory, and we have in the above circumstances one of the best means of determining the actual direction from which the force came. Another guide to the direction of the movement is this: The grooves are frequently found to radiate, sometimes at considerable angles, on reaching a certain point, as on meeting with some obstruction or with a change in the grade, especially when the slope is steep. I have observed the same thing happen to previously

parallel grooves on their leaving a slight depression on such slopes. The force would evidently come from the direction from which the grooves radiate.

Perhaps the readiest means of ascertaining the direction of movement is afforded by the crescent-shaped markings so frequently to be seen on glaciated surfaces, but which have not received the consideration they deserve in this connection. These markings follow each other at short intervals in rows parallel to the striæ, their convex sides being towards the quarter from which the movement came. These markings are generally from an inch to six inches in diameter. Wherever they occur they seem to indicate great pressure and appear to have been caused by hard stones firmly held in the lower surface of compact ice moving forward *per saltum*, as if they had stopped at each interval and actually crushed into the rock-surface by the stupendous weight above, and then to have been forced along again a short distance when another stop and another bruise in the rock occurred.

When unaltered strata lie at low angles upon a nucleus of crystalline rocks, there is a marked difference in the effects produced by the action of the passing ice-sheet according as the latter moved from the overlapping strata onto the solid nucleus or off the latter against the upturned edges of the stratified rocks. In the former case no valleys are formed, and there is nothing in the topography to indicate the junction of the two formations; but in the latter, great erosion has always taken place and valleys and basins are formed whose width depends largely on the angle of dip and the softness of the strata which have been scooped out. The strata are presented in the most favorable attitude for abrasion, especially when they have been cracked by transverse anticlinals. The wearing-down process would go on till the resisting rock-front had attained a height and weight sufficient to counterbalance those of the glacier. The excavating process would be greatly aided by the tendency, which seems to exist, of the rocky débris to rise from the base over heights lying in front, in the direction of movement. These excavations are now generally occupied by lakes or channels, or they form valleys of rivers. The St. Lawrence below Quebec, the North channel of Lake Huron, and the long sounds of the east coast of Hudson's bay are cases in point. The last named lie between the mainland and the long chains of islands which run parallel to it. The islands are composed of stratified rocks, dipping westward into the sea and having steep bluffs facing inland or directly opposite to the general westward course of the drift along that coast. The basins of lakes Ontario, Erie, Huron, and Michigan, as well as that of Georgian bay, were excavated in a similar manner. Further north we have other examples of basins of erosion in lakes Winnipeg, Winnipegosis, Manitoba, Athabasca, and in Great Slave lake, not to mention innumerable smaller ones.

The Formation of Lake Basins.—Some geologists seem to hesitate to admit that the basins of the great lakes mentioned above could be formed in this way, on account of their extensive areas and the great depth of some of them. At the same time, they would probably not deny the glacial origin of thousands of smaller lake basins, which can be pointed out in Canada, where the whole evidence is presented to the eye in a very limited compass. There we can see simultaneously glacial striæ descending into the water on one side of the lake-basin and emerging on the other, while more or less drift material is deposited all around. Here we have no difficulty in realizing the whole process of the formation of these small lakes. We have only to enlarge our conceptions of nature to picture the formation of greater lakes by the same process, which is equally easy on any scale, no matter how large, if we can admit the forces to have been equal to the requirements; and why should we not? Why should we seek to limit the operations of Nature by bounds set through our own narrow conceptions?

Some lakes in the glaciated area, however, occupy sites of depressions which existed long before the drift period, and which may date far back in geological time. These may have been greatly enlarged or partly re-excavated by the action of the ice. Lakes Superior, Nipigon, Temiscaming (on the Ottawa), and St. John (on the Saguenay) are examples of such ancient geological depressions; but the grandest of all is Hudson's bay. The original basins of all these bodies of water have existed since Cambrian and Silurian or even earlier times. But there is abundant evidence of their having been enlarged by glacial action. The site of Lake Superior appears to have acted as a reservoir for the accumulation of ice, which again forced itself out in different directions. Reference has already been made to the fact that it moved westward from the northwest shore; and it had a general southward course for some distance from the south side. But the most curious feature in this connection is the fact that it moved eastward, and even northeastward, up the steep and rocky shores on the east side. Evidence of this may be seen on many parts of the coast, all the way from Michipicoten to Batchewana bay.

The wide but shallow basin of Hudson's bay is situated in the centre of the greatest area of glaciation in North America, and it offers the most interesting field for the study of the phenomena of the drift period, on account of both the grandeur of the scale on which the forces operated and the distinctness with which their records may be read at the present day. This great central basin of the continent stretches from the interior of the Labrador peninsula on the east to the Rocky Mountains on the west, and from Baffinland on the north to Minnesota and Dakota on the south; and it has, therefore, a diameter of two thousand miles each way. As already stated, the site of the present bay acted on a stupendous scale as a reservoir

for the snow-fall on its own area and as a collecting basin for the ice from the northwest and the east, and discharged it in vast sheets to the northeastward and the south and southwest. The ice-sheet from this quarter would be great enough to hold back the water of the hypothetical Lake Agassiz, although it is possible this may have been supported by other means. The general elevation of the land was probably greater than now, and when the ice melted towards the south, which it probably did rapidly, it may have discharged a tremendous stream of water over what is now the narrow divide between the head of Long lake and the north shore of Lake Superior. The area of pot-holes, remarkable for their number and great size, described by Mr. Peter McKellar in a paper printed in this volume, is in the track which would be followed by such a river.

Some extraordinary features with reference to glaciation are presented at the northeastern extremity of Hudson's bay. The northern part of the east coast of the bay runs about due north, while the western part of the south shore of Hudson's strait runs about due west, so that the two form a right angle at Cape Wolstenholme. Projecting westward from this cape are two high islands, called Digges, the Outer one lying west of the Inner, the latter being separated from the cape by a narrow notch. Overlooking Hudson's strait from Cape Wolstenholme, for twenty or thirty miles eastward, is a perpendicular precipice a thousand feet or more in height. It has a nearly uniform elevation; while, looking eastward from the Hudson's bay side, the plateau above it has an even outline, which appears to slope slightly upward to the brink of this great precipice. The angle formed between the south side of Inner Digges and the main land is bounded by high and almost perpendicular walls of rock. The glacial movement here having been from the west and south, it looks as if these walls had been protected by a wedge of ice, their height having been too great and their slopes too steep for the lower part of the glacier to surmount; while their peculiar conformation with regard to each other would aid in wedging the ice in the manner supposed. At a considerable distance to the southeast, or directly inland from the cape, some mountains rise to a height of perhaps a thousand feet above the plateau which has just been described. If the ice-sheet moved from south to north on this plateau, as it did on lower lands to the southward, and if the land was as high as it is at present, there must have been a magnificent ice-fall over this precipice in glacial times.

The great lakes of the St. Lawrence and our Northwest Territories are all on or near the junction of the Archean with newer rocks. The basins of some of them extend far below the level of the sea, or even below the bottom of Hudson's bay. Although this inland sea of Canada is filled with salt water, it may, geologically speaking, be considered as analogous to the great lakes rather than as forming part of the ocean. With its wide shallow basin,

its eastern border of Azoic and its western of Paleozoic rocks, it bears considerable resemblance to the vanished Lake Agassiz. If the Hudson's bay region were raised bodily and evenly only about 400 feet, all its waters would drain away, leaving an almost perfectly level plain unequalled for extent in North America, and with the largest river in the world flowing out at its northeastern angle; but if it were canted so as to give a grade as low as a single foot in the mile from north to south, it would separate from Hudson's strait and become a gigantic fresh-water lake, discharging by the continuous valley which follows the Albany and Kenogami rivers, Long lake, and the Black river to Lake Superior, passing near the site of the cluster of wonderful pot-holes described by Mr. McKellar. As the land was probably much more elevated than this in the north during the glacial period and the basin of Hudson's bay filled with fresh-water ice, it is not impossible that towards the close of the period this ice became liquefied and that for a time we really had a fresh-water lake larger than the present Hudson's bay. If this were so, Lake Agassiz, large as it was, would be completely dwarfed and Lake Superior, now the greatest lake in the world, would become a mere pond in comparison.

The enormous glaciated Archean region of Canada is preëminently the land of lakes, and has no parallel in the world. Leaving out the great border lakes already referred to, those within the limits vary in size from 170 miles in length, like Reindeer lake, down to a few hundred yards. Among lakes from 40 or 50 to 100 miles in length may be named Aylmer, Cree, North-lined, Wollaston or Hatchet, Reindeer, La Plonge, La Ronge, Montreal, South Indian, Burntwood, Simon, Split, Sipi-wesk, God's, Island, Trout, Lonely, St. Joseph or Osnaburgh, Rainy, Long, Temagami, Abittibi, Temiscaming, Keepawa, Grand, Nipissing, Mistassini, Michigama, and many others whose names are entirely unknown to geography. Lakes of smaller size count literally by the ten thousand. In some whole districts it is estimated that nearly one-half and certainly one-fourth of the entire area is occupied by these sheets of water. They are nearly all rock-basins, comparatively few of them being held in by moraines or loose material in any form. They often run in chains or systems, in different courses, thus forming canoe-routes by which one may travel in almost any desired direction. The lakes constituting these chains often discharge into one another by a succession of short links of river. The upper Ottawa, the English river, which discharges Lonely lake into the Winnipeg, and the Churchill from its source to where it enters upon the Paleozoic rocks, are among the examples of these chains of alternating lake and river.

Reäction of Rock Structure on Glacial Erosion.—The arrangement of the lakes in the patterns above referred to is due, originally, to glaciation in connection with preëxisting geological causes. Among these may be men-

tioned the dips and flexures of the strata, lines of crushing or fissures, with or without igneous injections, and unequal hardness of the rock—or rather its unequal susceptibility to decay. I have often noticed that lines of crushing which might not otherwise have been very observable are of much importance in promoting the decay of the rock, preparatory to its removal by glacial denudation, the different stages of the process being observable in the northern regions. The influence of dikes of breccia, trap, syenite, etc., in connection with erosion has been very considerable in determining the topography. The large and small dikes have frequently produced opposite effects. The former, being coarsely crystalline and decaying easily, have given rise to long valleys, now occupied by rivers or lakes, while the smaller ones, being close-grained, tough, and generally resisting disintegration well, have protected other rocks from the force of the glaciers, and they are now marked by ridges or by the chutes and falls which they cause in the rivers crossing their courses.

The effect of large dikes in thus producing channels for water is very conspicuous in some sections of the Mattagami river, as described in my Geological Survey report for 1875. In my report for 1870 I pointed out that the trough of Long lake, more than fifty miles in length and running at right angles to the strike of the crystalline rocks of the region, lies along the course of an immense dike. In 1878 the long, straight channel of Nelson river, from Sipi-wesk to Split lake, was shown to be due to a similar cause. Among other long sheets of water which have been excavated upon the run of large dikes may be mentioned Oba lake, north of Michipicoten; Pogamasing lake, near the intersection of the main line of the Canadian Pacific railway and the Spanish river; Onaping lake, a narrow channel thirty miles long, lying north of a station of the same name on the railway just mentioned; and Matatchewan lake, at the great bend of Montreal river. And I have no doubt that almost all the lakes of this Archean region which are tolerably straight and very long in proportion to their breadth will be found to occupy channels originally due to the existence of large dikes. Among such lakes may be named the Long lake, west of Lake of the Woods, and Lake Temiscaming on the Ottawa. The gorge of the Sagnenay, and even that of Hudson's strait, may be due to similar causes. The narrow rocky arm of Georgian bay which receives the Maganatwan river is situated upon a rift in the gneiss, filled in places with breccia, resulting perhaps from the grinding of its walls. It is probable that similar inlets in the vicinity, such as Collins inlet, The Key, and the peculiarly straight intersecting channels of the mouth of the French river, originated in similar fissures. Mr. E. B. Borron, J. P., who has travelled much in the regions north of lakes Huron and Superior, informs us that he has seen so many instances confirming the above view as to the origin of straight river-courses and long narrow lakes that he regards it as an established fact in regard to the topography of the country.

Lakes of Double Outlet.—The widespread Archean area of Canada, having nearly everywhere about the same general elevation, is naturally divided into many hydrographic basins. The water-sheds separating them are not well defined ridges but plateaus with such gentle slopes that it is often difficult to tell which side of the height of land one may be on, and there is an interlocking of the upper waters of rivers which flow to opposite sides. The country along these divides is so level and the streams are so sluggish that all the brooks are navigable by canoes. Lakes of various sizes, some of them being of the larger class, occupy these situations, and not infrequently they have two outlets discharging their waters in opposite directions. This condition could only happen in rock-basins where but little wear is possible; for if the outlets were over soft materials one of them would soon become deepened and the other would cease to flow. Among the more striking examples of this phenomenon which might be mentioned are the following: Wollaston or Hatchet lake, which sends out two rivers of equal size and each larger than the Mississippi at St. Paul, the one falling into Lake Athabasca and the other into Reindeer lake—that is to say, into the basins of Mackenzie river and Hudson's bay respectively; Summit lake, between Lake Nipigon and Albany river, which discharges equal-sized rivers northward by the Albany into Hudson's bay and southward by Lake Nipigon into the St. Lawrence. These streams are navigable without interruption for small boats for miles on either side of the lake, so that one may sail up one, through Summit lake and down the other without getting out of his craft.* In 1887 I passed through no fewer than five lakes with double outlets connected with different branches of the upper Ottawa between Lake Temiscaming and the source of the river.

The most remarkable instance of a lake with more than one outlet which I have met with is that of Lake Temagami, between Lake Nipissing and Montreal river. We have made a careful detailed survey of this beautiful sheet of water. It measures about thirty miles from north to south and the same from east to west, and has had until recently no fewer than four outlets, one towards each of the cardinal points. The east and west outlets have dried up, either from the deepening of the other two or from a very slight elevation on either side of the north and south axis of the lake. Some time ago the northern outlet was evidently the larger of the two yet running; but it is now smaller than the southern, and appears to be still diminishing, while the other is correspondingly increasing. This may be due to an extremely slight tilting in the surface of the country. A rise of a few feet in the water of the lake would set all four outlets flowing again.

Discordant Striæ.—In regard to the courses followed by the glaciers of the drift period, when the directions of the striæ in all parts of the country are

* Report of Progress, Geol. Survey of Canada for 1871–'72, page 107.

laid down upon a map, some degree of parallelism is shown within the various groups, yet the general bearings of these are so different that it is difficult to see how they could have all been produced contemporaneously or by a confluent ice-sheet; and yet, excepting far to the north, they all seem to be equally old, and to have the same relations to the till. If any great interval of time had elapsed between the production of these various sets of grooves we should see greater differences among them than we do. A satisfactory solution of the problem requires more study than it has yet received, but it seems possible that the different groups, nearly equally distant from the margin of the glaciated area, may have been produced within a few thousand years of each other, their varying directions being accounted for by changes in the slope of the land and by the greater or less quantity of ice existing at the time—the course of a deep and wide glacier influenced by the general contour of the country being different from that of a narrower one guided by the more local features. In this way nearly all the grooves which had been produced in a given region might be obliterated and replaced by another set within a comparatively short time, leaving only traces of the earlier ones behind. It would not, therefore, be necessary to suppose two distinct glacial periods to account for such facts.

Such changes in the direction of transportation would also serve to explain some of the facts in connection with the composition of the drift. In order to trace the distribution of the latter we require to choose some rock of a well-marked character, situated far enough north, whose position and boundaries are known. The peculiar and beautiful conglomerate of white quartzite matrix with red jasper pebbles which occurs, so far as we are aware, only at the east end of Lake Superior and in the adjacent country north of Lake Huron affords one of the best examples of this sort. Fragments of this rock are found to the eastward all along the northern shores of Lake Huron as far as French river, although the direction of the striæ in the interval and all around the northern part of Georgian bay is southwest. Worn pieces of the same rock have been met with in the counties of Bruce and Huron, and southward through the state of Ohio and into Kentucky. A large bowlder of this conglomerate, found in the southern part of the lower peninsula of Michigan, has been placed in the grounds of the State University at Ann Arbor. This wide lateral dispersion from a small center and partly across the direction of the existing striæ implies a shifting of the drift materials by successive glaciers pursuing different courses.

Lake Agassiz.—Let us now turn our attention for a few moments to Lake Agassiz. The writer, having explored pretty extensively in the country between the site of this former lake and Hudson's bay, which is the most interesting field of inquiry in connection with questions as to the possibility of the existence of such a lake, may be allowed to add some remarks to

what has already been said on this subject. It has been assumed by some geologists that, owing to the supposed lowness of the land, the front of a very wide glacier would be requisite in order that the water of this lake might have been sustained on the east; but no actual evidence has been offered, except by myself, that any glacier ever existed in that quarter. Although it would appear that the ice-sheet did at one time push its way from the bed of Hudson's bay, or even from the high lands of the Labrador peninsula to the east of it, across the intervening country, this agency may not have been necessary to account for the existence of the lake. The gap which would require to be stopped in order to dam up the water and cause it to spread over the shallow basin of Lake Agassiz is much narrower than is commonly imagined. Without supposing any change of levels, the water-shed between Lake Winnipeg and Hudson's bay is more than sufficiently high to retain the water till it comes within a very short distance of Nelson river. Then on the northwest side of this great stream the land rises rapidly below the junction of Burntwood river to a height of at least 500 feet above the main stream, and the Churchill flows in a valley much more elevated than that of the Nelson.

Great quantities of moraine matter are deposited on the western slope of Hudson's bay on all the routes which I have followed in travelling to it from the interior. It forms hills and ridges, through which the rivers have cut their way. Hill river, on the travelled route between Lake Winnipeg and York Factory, is so called from Brassy hill, a steep, conical mound of earth in the line of a great moraine, which rises to a height of 390 feet above the water at its base, where it is intersected by the river. This is, perhaps, higher than the level of Lake Winnipeg. From the top of this hill about twenty moraine lakes may be counted.

This paper is already too long, or many interesting facts might be given in reference to the intersection on other rivers of what may be the continuation of this moraine. But, judging from what I have seen on my own explorations and from what I have been told by local travellers, I may simply say it seems probable that a great terminal moraine may be traced along the western slope of Hudson's bay at a considerable distance inland and with an elevation of several hundred feet above the present level of its water. It is possible that at one time part of this moraine choked up the valley of Nelson river and flooded back the water of the Winnipeg basin so as to form Lake Agassiz. This would be rendered all the easier if the continent were slightly more elevated to the eastward than it is at present, and there is much reason for believing that it was so. The well-marked beaches of Lake Agassiz show that its waters were stationary at certain levels for a considerable time, which could scarcely be possible if its outlet were through or

over a glacier. There are various other strong objections to the theory of an ice dam, which cannot be discussed within the limits of this paper.

If, on proper investigation, it should turn out unlikely that the water of Lake Agassiz was held in its place by earth barriers in conjunction with a higher general level of the continent to the east, then we shall probably find that this ancient lake was a land-locked bay of fresh or nearly fresh water on the same level as the former extension of Hudson's bay. Had the continent been slightly elevated to the eastward, and had the north end of Hudson's bay at that time been about 1,000 feet higher than at present, relatively to the narrow divide between Long lake and Lake Superior 1,000 miles to the south, the fresh water which we have supposed would then fill this great basin might easily have been on the same level with Lake Agassiz, and the latter would then have been a mere bay of the former. A whitish clay of similar character is spread widely over both areas; and it is significant that no marine shells are to be found in any of the post-Tertiary deposits in either of these areas until we have descended to within 500 feet of the sea-level on the Attawapishkat river, and 200 feet lower on the various branches of the Moose river at a distance of 200 miles to the south. The shells are found in similar stratigraphical positions in both cases, and their difference in level corresponds with the rate of slope (one foot in the mile) which would exist had the supposed relative change of levels occurred.

Upward Movement of Bowlders.—The elevation of bowlders from lower to higher levels is a curious phenomenon in connection with drift transportation. In the lake peninsula of the province of Ontario, the débris of the Hudson River and Niagara formations has been carried westward in great quantities and scattered over the surface of rocks which are higher both geologically and geographically. In the valley leading westward from the head of Lake Ontario, the ice-grooves are plainly seen on the rocky walls on either side sloping gradually upward; but to the north of this valley there is an almost continuous east-facing precipice all the way to Georgian bay, which the ice-sheet would require to surmount. The Silurian table-land above this precipice slopes gradually upward, as we go north, from about 400 feet above Lake Ontario to upwards of 1,500 feet over the same level when it reaches Georgian bay and forms the Blue Mountains. Laurentian bowlders from the comparatively low region north of Georgian bay, are found everywhere upon this table-land.

In the chapter on superficial geology in the "Geology of Canada" (1863, page [illegible]), I stated, from my own observations, that "bowlders of Laurentian rocks are found in considerable numbers scattered over the high table-land of western Canada south of Georgian bay. A portion of this region attains an elevation of 1,760 feet above the sea, and much of it is higher than the Laurentide hills to the north, from which the bowlders have been

derived. These blocks are generally more angular than those from a similar source found at lower levels, and are associated with many others of local origin."

In approaching the base of the Niagara escarpment anywhere from Lake Ontario to Georgian bay, or along its continuation to the northwestward through the Indian peninsula and the Manitoulin islands, one cannot fail to remark the absence of any considerable talus or accumulation of the waste of the former extension of the strata composing the cliff. The fallen blocks, except the most recent ones, have all disappeared, and we find them perched up on the brink or scattered on the plateau above it, instead of strewn over the lower lands at its foot, where we might have naturally looked for them. On the west side of Lakes Manitoba and Winnipegosis an east-facing escarpment of nearly horizontal Cretaceous strata rises to a height of about a thousand feet in the form of the Riding and Duck mountains. The table-land of these mountains is, in many parts, strewn with Laurentian bowlders derived from the lower-lying Archean region east and northeast of Lake Winnipeg, showing a great uplifting of the erratics by the glacier-sheet. The bowlders are occasionally deposited in ridges and hummocks, some of which are mentioned in my report for 1874.

In the report for 1873 on the Northwest Territory, I showed that the drift of the country between the Laurentian region and the Coteau de Missouri came from the northeastward, and that it consists of "Laurentian gneiss, granite, syenite, and the crystalline schists of the Huronian series, together with a large proportion of compact, buff, drab, and gray limestone;" also that the front of the Coteau itself "consists in reality of the ruins of an escarpment;" and that "the force which had undermined it had evidently acted from the northeastward." The high ground of the Coteau was further described as very rough and covered with the above kind of drift. Many of the Laurentian bowlders are angular, and they "are so numerous over considerable areas that a man might walk upon them in any direction without touching the ground." * The front of the Coteau was ascertained by barometer to rise from 600 to 700 feet above the plain immediately to the north of it. The hills of drift above the Coteau are steep and generally conical, and resemble, on a grand scale, the appearance of stiff stony earth newly dumped in separate piles close together. The hollows between these hills contain numerous ponds and small lakes. As the foot of the Coteau is probably as high as the average of the Laurentian surface to the northeast, if not higher, the ice-sheet must have been able to elevate this vast quantity of drift to the above heights.

The angular character of many of the bowlders which have been raised to the various elevated areas just described is an interesting fact, and it

* Rep. of Progress Geol. Surv. Can. for 1873, 1874-'75, page 43.

seems to indicate that these bowlders have been carried either in the midst of the ice or on the back of the glacier, which they must have reached by passing upward through its substance by some process which has not yet been clearly demonstrated.

I noticed that where the supposed great terminal moraine of the western slope of Hudson's bay is crossed by the Churchill, Little Churchill, Nelson. and Hill rivers, a large proportion of the bowlders were angular. This appeared to be more especially the case on Hill river, where the stream flows for miles on a bed of angular Laurentian bowlders in the section which traverses the supposed moraine.

The Period of Glaciation.—In attempting to estimate the time which has elapsed since the glacial period, everyone is struck by the freshness of the striæ on many glaciated surfaces, and might argue from such evidence that this period was not so remote as most geologists have hitherto supposed. It will be found, however, that most of the well-preserved surfaces have been protected from the weather during the greater part of the time that has elapsed, either by water, which has since disappeared but of which we see so much evidence, or by earth which has recently been removed. Even the waters of the present lakes and rivers have a great effect in preserving the striæ. In the Laurentian lakes they are wonderfully sharp and distinct under the low-water mark, whereas the continuations of the same grooves on exposed surfaces are almost obliterated, although the hard and smoother surfaces of the glaciated rocks are well calculated to withstand the influences of time. On unaltered rocks which have been long exposed the ice-grooves are entirely gone, and the surfaces which we know by their outline must have been glaciated are crumbled or eroded.

In the county of Argenteuil, Sir William Logan described veins of quartz cutting crystalline limestone where the striated surfaces of the former stand out from six to nine inches above the general surface of the latter, showing that the limestone has been dissolved away to that depth since the striation took place; but this may have all been done during only a part of this interval. I have seen many other cases both in Argenteuil and Ottawa counties where hard veins and lumps embedded in crystalline limestone and bearing the striæ are weathered out to various heights not exceeding one foot above the roughened but sound surface of the limestone.

After all, the surface of any stone hard enough to be used in the building of important structures withstands the influence of the weather for long periods, as proved by many examples in Italy, Greece, and Palestine, and more particularly in Egypt and Central America. A smooth and sound rock-surface produced by glacial rubbing and polishing is better adapted to endure the ravages of time than any artificially hammered surface. The destructive influences of time appear to operate even more slowly in cold

regions than elsewhere. Oxidation and decay of all kinds are slower than under the influence of heat and the rapid growth of all the various lower forms of plant and animal life. Not only are marks on rocks preserved in an extraordinary manner in northern climates, but the great durability of timber has been remarked by travellers in Norway and the Arctic regions of Canada. Logs of such perishable wood as spruce, which even in this latitude would disappear through decay in a few years, are found in a sound state in the latter regions, where they have probably lain for thousands of years. Even on the east coast of Hudson's bay I have recorded the occurrence of lines of drift-wood, principally spruce and cedar, on raised beaches thirty feet above the highest tides, which would indicate a period of over 400 years, even if the rate of elevation were as rapid as my supposition of seven feet in a century.

The deposition of the thick sheets of till over the well-preserved grooved surfaces at any given place could not have been quite contemporaneous with the making of the grooves themselves, but must have required time. Again, we should take into consideration the many things requiring great length of time which have taken place since the till was left upon the surface of the rocks, such as the submergence of the land and the deposition of various stratified clay and sand formations upon it. At Ha-ha bay, on the Saguenay, the stratified clay of the Champlain formation, which overlies the drift, has a thickness of upwards of 600 feet; and in the valley at the head of Lake Ontario the clay above the till is at least 200 and may be 400 feet thick. The stratified gravels and sands of Burlington heights at this locality rise 107 feet above the lake, and are also sunk below it. These deposits lie upon the stratified blue clay of the Erie formation, which in turn rests upon the till.

We cannot suppose that the change from the glacial condition to something like the present climate of North America was a sudden one. The transition, whether brought about by astronomical causes or only from changes in the elevation and distribution of the land and in the currents of the ocean, must have been very slow. It is therefore very improbable that the ice disappeared from all parts of the continent at the same time. There must have been a gradual and progressive recession northward of the general glacial condition, which may not yet have entirely ceased. Glaciers are said to exist still in some parts of Baffinland. It is, however, more probable that we have passed the period of greatest warmth, and that a colder condition has again begun to creep upon us from the north. The continued elevation in polar regions, historical facts in Greenland, the southward retreat of the verge of the forests, and other circumstances favor this view.

Southward of the central regions of dispersion it may be assumed in a general way that the time which has elapsed since the disappearance of the

ice at any locality varies to a great extent with its latitude, so that the antiquity of the glacial groovings and drift deposits of the district between Pennsylvania and Nebraska in the south and those of the latitude of the center of Hudson's bay in the north may and probably does differ by many thousands of years. In order to attempt some kind of calculation of time based on a given rate of recession of the ice-sheet for this distance, let us for the moment set aside all other questions that might complicate the problem and try to obtain some idea as to how long it might take for the simple and direct recession of the ice, say from the latitude of Cincinnati to that of the most southern glaciers of Baffinland. Cincinnati is in latitude 39° and the reputed glaciers of Baffinland in about 65°, a difference of twenty-six degrees. If the average retreat of the ice-sheet was as rapid as one degree in a thousand years, which is probably above the mark, it would require 26,000 years to recede from its southern limits to the regions where the glacial condition is possible at this day.

On Portland promontory on the east coast of Hudson's bay, in latitude 58°, and southward the high rocky hills are completely glaciated and bare. The striæ are as fresh-looking as if the ice had left them only yesterday. When the sun bursts upon these hills after they have been wet by the rain they glitter and shine like the tinned roofs of the city of Montreal. Yet even here it must have been a good many thousand years since the glaciers disappeared.

In my report for 1884 I described the occurrence of the handiwork of the Eskimos on Outer Digges island, indicating a lapse of at least one thousand years; and still the time which has gone by since these people built their dwellings and their stone fish-traps on the beaches then washed by the sea, but now elevated seventy or eighty feet above its level, must have been short compared with the days when great ice-sheets from the interior slid down the rocky slopes on the foot of which these beaches lie.

The recession and disappearance of the ice-sheet is, however, only one of the elements to be taken into account in trying to arrive at some estimate of the time which has elapsed since the deposition of the till along its southern extension. We have to consider the submergence and elevation of the land which followed. These movements are extremely slow, and would require at least double the above time, or over 50,000 years, for their accomplishment. At Nachvak, on the eastern coast of Labrador, raised beaches show with great distinctness at an elevation of about 1,500 feet above the sea. The land might have been 2,000 feet higher than at present at the time of the greatest accumulation of ice. This would represent a depression of 3,500 feet and a subsequent elevation of 1,500 feet. If the rate of vertical movement were as rapid as seven feet per century, the depression and elevation proved by the existence of these beaches would require upwards of

42,000 years; but it was probably much slower than this on an average and there must have been a long stationary period when these beaches were forming, so that the estimate of Dr. James Croll, Dr. James Geikie and others of 80,000 years as the time which has elapsed since the glacial period in Great Britain and the inhabited parts of North America need not be considered excessive.

The Cause of Glaciation.—In regard to the formation of the vast quantities of land-ice of the glacial period, it is a common error to suppose that its accumulation was due to intense cold alone. The production of glaciers was due to the same causes then as now, namely, a warm ocean with high land so situated that the air coming from the water laden with moisture might pass over the cold land and precipitate the vapor upon it in the form of snow. There is reason for believing that the Laurentian area of Canada and the northern part of the Appalachian region were much higher in the glacial period than now. The great precipitation of snow which took place over these areas may have been due to an extension at that time of the Gulf of Mexico over part of the Mississippi valley. The Gulf Stream, perhaps of greater volume then than now, would eddy round the enlarged Gulf, giving an immense evaporating surface, and, passing round the southern part of the Appalachian range, would flow northwestward close to this continent, being protected from the Arctic current by the dry land which would take the place of the now submerged banks of Newfoundland. If the weather circles or ellipses travelled in courses corresponding to those which prevail at the present time, we should thus have the most favorable conditions for the rapid accumulation of ice all over the area which has been glaciated.

The Causes of Changes in Level.—What caused the depression of the land at the close of the drift period? The suggestion that it may have been due to the weight of the ice itself bending down the crust of the earth is worthy of consideration, although this explanation would be more obvious had the depression taken place while the weight was upon it, and not after its removal. The subsequent elevation, which is still going on, may be the slow return of the outline of this part of the earth's surface to its normal curve. It is generally accepted that ice acts as a semi-fluid, and therefore it must be subject to hydrostatic laws. Many facts in geology go to show that rocks, too, on a large scale have manifested a sort of plasticity without having undergone igneous softening. May not the whole globe of the earth slowly follow these laws, even if its interior be not in a liquid condition? The slightest sensible pressure on any part of its surface would be followed by an effort to regain its perfect equilibrium. But the elevation of the land above the general level of the ocean, which is still in progress in north polar regions, may be something more than a mere upheaval of part of the crust of the earth. It may be, as Dr. Croll supposed, an actual retiring of the

sea, due to a slight shifting of the centre of gravity of the earth on account of the accumulation around the south pole of the mass of ice, a mile thick and 2,000 miles in diameter, which is believed to exist there. In the northern portions of America, along with this general movement, local elevations and depressions may also be going on. But the evidence of the numerous Arctic voyagers who have visited nearly all parts of the northern regions of the Dominion shows that this movement is taking place with apparent uniformity throughout this large area of the earth's surface.

Towards the close of the period of depression following the glacial era, the northern parts of lakes Huron and Superior must have been relatively lower than the southern in order to account for the well-marked terraces and beaches which we find at various elevations up to more than 300 feet above the levels of their present outlets, as there is no evidence of barriers of any kind having existed in their neighborhoods in such recent times. The Davenport ridge behind Toronto, and gravel ridges at the head of Lake Ontario, prove that its waters stood at least 170 feet higher than now at some time since the glacial period; and, as there are no remains of a barrier at its east end, it is probable that the bed of the St. Lawrence below it was so elevated as to keep back the waters to this additional depth. The evidence thus afforded by some of the great lakes of the St. Lawrence goes to confirm the theory of a former depression and subsequent elevation of the continent towards the north and east.

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ON THE PLEISTOCENE FLORA OF CANADA.

BY SIR WILLIAM DAWSON, F. R. S., AND PROFESSOR D. P. PENHALLOW, F. R. S. C.

(*Read by abstract before the Society December* 28, 1889.)

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I. GEOLOGY OF THE DEPOSITS. BY SIR WM. DAWSON.

GENERAL GEOLOGY OF THE PLEISTOCENE.

The Pleistocene deposits of Canada may be defined as consisting of three principal members, which may be characterized as follows, in ascending order:

1. The Till, or lower bowlder clay, a tough or sometimes sandy clay, containing local and traveled stones and bowlders, often glaciated. It usually rests on glaciated surfaces, but is sometimes underlain by stratified gravels or by old soil surfaces or peaty beds. These are, however, rare and local.* In the more maritime regions—*e. g.*, in the lower St. Lawrence—it contains marine shells of arctic species. Farther inland—*e. g.*, in western Ontario and in the plains west of Red river—it is not known to hold marine remains.

2. Stratified clays and sandy clays. In the more maritime regions these are the lower and upper *Ledà* clays, holding many marine shells of boreal rather than arctic types, especially in the upper part. They also contain locally, drift plants, insects, and land or fresh-water shells, indicating the

* Acadian Geology, 1878, p. 63.

proximity of land clothed with vegetation. In the interior they are, so far as known, destitute of marine remains, but hold remains of land plants and even beds of peat with a few fresh-water shells. These beds are those known in the interior region as "interglacial." They seem to vary much locally in composition and thickness, and are sometimes absent. Where they are absent or replaced by bowlder clay, the latter occasionally contains drift trunks and branches of trees.

3. Sands, coarse clays, and gravels, often stratified, sometimes containing traveled bowlders throughout. In other cases there are bowlders at the base of the deposit and also at its surface, the intervening beds being destitute of bowlders. In the maritime regions these beds often contain marine shells and are the *Saxicava* sands and gravels. Inland they are unfossiliferous or have a few drift plants, sometimes of sufficient importance to be reckoned as a second or upper interglacial bed. These beds constitute the upper or newer bowlder formation. Their traveled bowlders are often of great size, and have been as a whole carried farther and deposited at higher levels than those of the older bowlder formation.

Above the third member are alluvial deposits, lake terraces, gravel ridges and eskers, prairie silt, peat beds, etc., which may be regarded as early modern or post-Glacial.

More detailed descriptions of the Pleistocene deposits of Canada will be found in the author's "Notes on the Post-Pliocene of Canada;"* also in his "Acadian Geology" and "Handbook of Canadian Geology."†

Fossil plants appear in these deposits in various places, from the Atlantic coast to the base of the Rocky Mountains and even in Queen Charlotte's islands; but the species are not numerous, and for the most part those now indigenous to the boreal regions of America, while their state of preservation is usually very imperfect.

As might be expected, vegetable remains in the Pleistocene are not confined to Canada, but occur very extensively in the United States. Whittlesey, Worthen, Andrews, Orton, Newberry, and others have referred to deposits of this kind in Illinois, Indiana, Ohio, and Minnesota; and in the "Proceedings of the American Association" for 1875 Professor N. H. Winchell has summed up what was known up to that date, and has noticed more than fifty localities of the "forest beds," as these accumulations are called. Professor Worthen has recognized two distinct forest beds in Illinois, one immediately below the loess, the other under till or true bowlder clay. The latter he says extends over nearly the whole of central and southern Illinois. Though I have had specimens kindly sent to me by Professor Worthen, Dr. Andrews, and others, I do not propose to enter into any details on these deposits in the United States, but merely to refer to their extension from Canada to the southward as important in a geological sense.

*Canadian Naturalist, new ser., vol. VI, 1871, p. 11, et seq. †Montreal, 1889.

The observed sequence of deposits may be understood by the subjoined sections, which represent respectively the arrangement in the St. Lawrence valley at and below Montreal as observed by the author; that on the north shore of Lake Ontario as given by Dr. J. G. Hinde;* and that in the vicinity of the Belly river, North West Territory, as noted by Dr. G. M. Dawson.†

	Montreal and lower St. Lawrence. J. WM. DAWSON.	*North shore of Lake Ontario.* J. G. HINDE.	*Belly river, North West Territory.* G. M. DAWSON.
	I. Surface soil, post-Glacial alluvia and peat.	I. Surface soil, stratified sand, and gravel.	I. Surface soil and prairie alluvium.
Pleistocene.	II. Surface bowlders, *Saxicava* sand and gravel. Bowlders in and below sand.	II. Bowlders, sand, etc. Laminated clay. Bowlder deposit.	II. Upper bowlder deposit.
Pleistocene.	III. Upper *Leda* clay, marine shells, and drift plants. Lower *Leda* clay, marine shells, and drift plants.	III. Stratified sand and clay, with fresh-water shells and plants.	III. Gray sand with ironstone nodules. Brownish sandy clay. Carbonaceous layers and peat. Gray sand and ironstone.
Pleistocene.	IV. Lower bowlder clay or till. Many native and some traveled bowlders. A few marine shells of arctic species.	IV. Lower bowlder clay or till. Native and traveled bowlders.	IV. Lower bowlder clay. Many traveled bowlders.
	V. Paleozoic rocks, often striated.	V. Paleozoic rocks, often striated.	V. Probably Cretaceous beds.

The above sections show a general correspondence in the series of deposits, except that in the sections on Lake Ontario, especially in that at Scarboro' heights studied by Hinde, we find a division of the upper bowlder deposit not so evident in the other sections.

There is no reason to doubt that the three members of the Pleistocene indicated as II, III, and IV are approximately contemporaneous in the different districts, and that No. III represents the usual interglacial period throughout North America. At the same time it is to be observed (1) that

* Canadian Journal, 1877, p. 339, et seq. † Report Geol. Survey of Canada, 1884, p. 144 C, et seq.

these deposits occur at different levels in the East and in the West; (2) that the lower bowlder clay belongs more especially to the lower levels in the several localities, while the bowlders of the second bowlder period have been carried to higher points; (3) that there is evidence in the interglacial period of the local prevalence of sea and land, of lakes, bogs, and dry ground; (4) that these several conditions may in the course of elevation and subsidence have migrated from one level to another, and (5) that while there is thus a general correspondence, there may have been some local diversity of date and transference of certain conditions of deposit from one locality to another according to the progress of subsidence or elevation.

This is so well illustrated by the observations of Captain Fielden in Grinnell Land, that I quote a part of his statements on the subject, as probably illustrative of the condition of Canada in the Pleistocene period.*

"In Grinnell Land, from lat. 81° 40′ N. to lat. 83° 6′ N., no glaciers descend to the sea, no ice-cap buries the land; valleys from which the snow is in a great measure thawed during July and part of August stretch inland for many miles, and the peaked mountains, snow-clad during the greater portion of the year, in July and August have great portions of their flanks, which rise to an altitude of 2,000 feet, bared of snow.

"The opposite coast of Greenland presents a very different aspect. A mer-de-glace stretches over nearly its entire surface; its fiords are the outlets by which its great glaciers protrude into the sea. In Petermann Fiord the ice-cap, with its blue jagged edge lying flush with the face of the lofty cliffs, was estimated to be forty feet thick.

"When we turn to the flora and fauna of Grinnell Land the difference is equally astonishing; some fifty or sixty flowering plants are found in its valleys, and between latitudes 82° and 83° N. I have seen tracts of land so profusely decked with the blossoms of *Saxifraga oppositifolia* that the purple glow of our heath-clad moors was brought to my recollection.

"Musk oxen in considerable numbers frequent its shores; the Arctic fox, the wolf, and ermine, with thousands of lemmings, live and die there. The bones of these mammals, along with those of the ringed seal (*Phoca hispida*), are now being deposited in considerable quantities in the fluvio-marine beds now forming in the bays and at the outlets of all the streams, or rather summer torrents of Grinnell Land. With these bones will be associated those of birds, such as geese and sea-gulls. Numerous mollusca and crustacea, many species of rhizopods, with the remains of land and sea plants, will there find a resting place.

"Supposing that these beds were examined at some future period under conditions when the glacial epoch had disappeared from the surrounding area, it would be difficult to realize that they were contemporaneous with the beds formed under the Greenland ice-cap in the same parallel of latitude and on the opposite shore of a channel not twenty miles across.

"In the one case enormous thicknesses of till with ice-scratched stones have in all probability been deposited; in the other, fluvio-marine beds containing a comparatively rich assemblage of marine and land forms, with river-rolled pebbles, would be brought to light."

*Proceedings Royal Dublin Society, 1878; see also, Quart. Jour. Geol. Soc., vol. 34, 1878, p. 565, et seq.

SPECIAL LOCALITIES OF FOSSIL PLANTS.

The plants referred to in Professor Penhallow's paper are derived in part from deposits belonging to each of the columns in the above table.

(1.) At Green's creek, on the Ottawa river, the *Leda* clay, there containing marine shells (*Leda arctica*, etc.) and bones of *Capelin* in nodules in the clay, has in its lower part nodules with leaves, seeds, and fragments of wood. These have been collected by the late Mr. Billings, Dr. R. Bell, the late Sheriff Dickson, of Kingston, the late Mr. J. G. Miller, and the writer, and were noticed in a paper by the writer on the "Evidence of fossil plants as to the climate of the Post-Pliocene in Canada," published in the Canadian Naturalist in 1866. These constitute a considerable part of the specimens described below. A few specimens of wood have also been found and noticed by the writer in the *Leda* clay of Montreal, and the available collections have been augmented since 1866 by additional specimens from Green's creek acquired by the Peter Redpath Museum of McGill University.

(2.) The interesting deposits at Scarboro' heights and elsewhere on Lake Ontario were described by Dr. J. G. Hinde in the Canadian Journal in 1877, and he notices the following plants as found by him:

Wood of pine and cedar.
Portions of leaves of rushes, etc.
Seeds of various plants.
Hypnum commutatum.
H. revolvens.
Fontinalis.
Bryum.
Chara, sp.

More recently Mr. J. Townsend, of Toronto, was so fortunate as to find leaves and fragments of wood with shells of *Melania* and *Cyclas*, in beds apparently of the same age, in excavations in progress on the River Don, at Toronto. These collections have been acquired for the Peter Redpath Museum. The section observed at this place is given as follows by Mr. Townsend:

The locality of the principal vegetable specimens was 150 feet from the bank of the Don, and in a cutting 70 feet deep. The section showed 26 feet of fine light-colored sand with layers of clay at bottom. Below this were 24 feet of tough stratified blue clay, the "Erie clay" of the region. At the base of this clay is a seam of reddish ferruginous sand about three feet thick, and with argillaceous nodules in which was the maple leaf described by Professor Penhallow. Below this sand were sixteen feet of alternating sand and dark-colored clay, with fresh-water shells and wood. Below this was the blue till resting on the surface of the Hudson river beds. In this section

the upper bowlder clay of Hinde's section is not represented, but only the groups III and IV as given in the table. The upper bowlder clay is, however, seen on higher ground in the vicinity.

Dr. J. W. Spencer, who has studied this locality, as well as the whole north shore of Lake Ontario, writes to me that he regards the earthy sand holding wood and fresh-water shells as equivalent to Hinde's "interglacial" beds at Scarboro' heights, and the overlying clay as the so-called "Erie clay," over which, as above stated, is the upper bowlder deposit which in the vicinity of Toronto has many Laurentian bowlders.

(3.) Many observations have been made on the interglacial beds by Dr. G. M. Dawson, and are recorded with sections in his reports on the 49th Parallel and on the geology of the Bow and Belly rivers, and in a paper on borings made in Manitoba and the North West Territories in Vol. IV of the Transactions of the Royal Society of Canada; and he has placed in our hands specimens of peat and wood from those regions. In one locality on the Belly river he finds a bed of interglacial peat hardened by pressure in such a manner as to assume the appearance of a lignite.

(4.) In addition to the vegetable remains found as above stated in the "forest beds" or "interglacial" deposits, trunks of trees and vegetable fragments occur in the bowlder clays themselves, indicating either the partial destruction of the older interglacial bed and the mixture of its débris with glacial deposits, or the enclosure of drift-wood in the latter in the manner now so common in the arctic regions and described by so many arctic explorers.* This raises very interesting questions respecting the origin of the bowlder clay, to be noticed in the sequel.

One of the most marked illustrations is that of the boring at Solsgirth, in Manitoba, on the Manitoba and Northwestern railway, and at an elevation of 1,757 feet above the sea.† At this place the section is as follows:

	Feet.
1. Loam	2
2. Hard blue clay and gravel	42
3. Hard blue clay and stones	10
4. Hard yellow "hard pan"	12
5. Softer bluish clay	16
6. " " "	74
7. Sand with water	--
8. Blue clay with stones	136
9. Gray clay or shale (Cretaceous?)	68
	360

Fragments of wood, more or less decayed and compressed, were obtained from depths of 96, 107, 120, and 135 feet from the surface. They were thus distributed through a considerable thickness of the clay rather than in a

* See Manual of the Natural History, Geology, and Physics of Greenland, by Professor T. R. Jones, issued by the Royal Society of London, 1875, index—"Driftwood."

† Dr. G. M. Dawson, Trans. Royal Society Canada, vol. IV, 1887, sec. IV, p. 91, et seq.

distinct interglacial deposit. It is to be observed, however, they were included within the central part characterized as a softer blue clay, between two beds apparently harder and more stony.

Additional specimens from this place have recently been obtained by Mr. J. B. Tyrrell, of the Geological Survey of Canada, and have been kindly communicated to us. Mr. Tyrrell has also found vegetable remains in a bed under the bowlder clay at Rolling river, Manitoba, which are noticed in Professor Penhallow's paper. They were accompanied with fresh-water shells of the following species, determined by Mr. Whiteaves, F. G. S., Palæontologist to the Geological Survey of Canada:

Lymnea catascopium ?, variety with very short spire.
Valvata tricarinata, and a keelless variety.
Amnicola porata ?
Planorbis parvus ?
P. bicarinatus.
Pisidium abditum.
Sphærium striatinum.

With these was the centrum of a vertebra of a small fish.

(5.) The most western locality of bowlder clay with plants is that described by Dr. G. M. Dawson in the vicinity of Skidegate, Queen Charlotte's islands. At this place hard bowlder clay is overlain by stratified sand and gravel, ten to fifteen feet in thickness. The bowlder clay in places shows bedding and holds a few marine shells (*Leda fossa*, etc.). In tracing the bed along the coast the shells disappear and the clay is found to contain fragments of decayed and partially lignitized wood. Specimens of this were collected, but appear to have been mislaid and could not be found in time for this paper.*

(6.) The most eastern locality from which I have collected Pleistocene plant remains is that on the northwest arm of the River Inhabitants in Cape Breton, described in "Acadian Geology," p. 63. This is a hardened peaty bed resting on a gray clay and overlain by twenty feet of till or bowlder clay, apparently the lower bowlder clay. It is quite hard and burns with flame in the manner of a lignite, and contains twigs and branches of coniferous trees and a great variety of fibrous and epidermal tissues apparently of swamp vegetation, which have been examined by Professor Penhallow. This locality is of special interest as showing a bed of vegetables evidently not drifted and under the till or bowlder clay. It shows that this was deposited on what had been a land surface and under circumstances which did not disturb a bed of soft vegetable matter. It indicates also a mild climate preceding the deposit of the bowlder clay rather than an interglacial period. There was no evidence in this case of any land-slip or other accidental disturbance, but rather of successive depositions.

* Report Geol. Survey of Canada, 1878–'9, p. 91B.

With reference to these I shall first refer to the district from the Atlantic to the head of Lake Ontario.

In this district and the eastern part of North America generally, it is, I think, universally admitted that the later Pliocene period was one of continental elevation, and probably of temperate climate. The evidence of this is too well known to require re-statement here. It is also evident, from the raised beaches holding marine shells, extending to elevations of 600 feet, and from bowlder drift reaching to a far greater height, that extensive submergence occurred in the middle and later Pleistocene. This was the age of the marine *Leda* clays and *Saxicava* sands found at heights of 600 feet above the sea in the St. Lawrence valley nearly as far west as Lake Ontario.

It is reasonable to conclude that the till or bowlder clay under the *Leda* clay belongs to the intervening period of probably gradual subsidence, accompanied with a severe climate and with snow and glaciers on all the higher grounds, sending glaciated stones into the sea. This deduction agrees with the marine shells, bryozoa, and cirripedes found in the bowlder deposits on the lower St. Lawrence, with the unoxidized character of the mass, which proves subaquatic deposition, with the fact that it contains soft bowlders, which would have crumbled if exposed to the air, with its limitation to the lower levels and absence on the hill-sides, and with the prevalent direction of striation and bowlder drift from the northeast.*

All these indications coincide with the conditions of the modern bowlder drift on the lower St. Lawrence and in the arctic regions, where the great belts and ridges of bowlders accumulated by the coast ice would, if the coast were sinking, climb upward and be filled in with mud, forming a continuous sheet of bowlder deposit similar to that which has accumulated and is accumulating on the shores of Smith's sound and elsewhere in the arctic, and which, like the older bowlder clay, is known to contain both marine shells and drift-wood.†

The conditions of the deposit of till diminished in intensity as the subsidence continued. The gathering ground of local glaciers was lessened, the ice was no longer limited to narrow sounds, but had a wider scope as well as a freer drift to the southward, and the climate seems to have been improved. The clays deposited had few bowlders and many marine shells, and to the west and north there were deposits of land plants, and on land elevated above the water peaty deposits accumulated.

The shells of the *Leda* clay indicate depths of less than 100 fathoms. The numerous foraminifera, so far as have been observed, belong to this range,

* Notes on the Post-Pliocene: Canadian Naturalist, op. cit.; also paper by the author on Bowlder Drift at Metis, Canadian Record of Science, Vol. II, 1886, p. 36, et seq.

† For references, see Royal Society's Arctic Manual, London, 1875, op. cit.

and I have never seen in the *Leda* clay the assemblage of foraminiferal forms now dredged from 200 to 300 fathoms in the Gulf of St. Lawrence.

I infer that the subsidence of the *Leda* clay period and of the interglacial beds of Ontario belongs to the time of the sea beaches from 450 to 600 feet in height, which are so marked and extensive as to indicate a period of repose. In this period there were marine conditions in the lower and middle St. Lawrence and in the Ottawa valley, and swamps and lakes on the upper Ottawa and the western end of Lake Ontario; and it was at this time that the plants described in this paper occupied the country. It is quite probable, nay certain, that during this interglacial period re-elevation had set in, since the upper *Leda* clay and the *Saxicava* sand indicate shallowing water, and during this re-elevation the plant-covered surface would extend to lower levels.

This, however, must have been followed by a second subsidence, since the water-worn gravels and loose, far-traveled bowlders of the later drift rose to heights never reached by the till or the *Leda* clay, and attained to the tops of the highest hills of the St. Lawrence valley, 1,200 feet in height, and elsewhere to still greater elevations. This second bowlder drift must have been wholly marine, and probably not of long duration. It shows no evidence of colder climate than that now prevalent, nor of extensive glaciers on the mountains; and it was followed by a paroxysmal elevation in successive stages till the land attained even more that its present height, as subsidence is known to have been proceeding in modern times.

The above sequence applies to the districts of Ontario, Quebec, the arctic coast, and the maritime provinces, and might be illustrated by a great accumulation of facts; but these may be found in papers published in the Canadian Naturalist and the Canadian Record of Science and in the reports of the Geological Survey, more especially those by Dr. G. M. Dawson, Mr. Chalmers, and the writer.

For the region between the great lakes and the Rocky Mountains and for the Pacific coast the sequence is similar, but either the interior region has experienced a greater elevation or the times must have been somewhat different. In the mountainous regions of the west, also, more especially in the interior of British Columbia, the evidence of great local glaciers is much more pronounced than on our lower mountains of the east.*

I am quite aware that the above sequence and the causes assumed are somewhat different from those held by many geologists with reference to regions south of Canada, but must hold that they are the only rational conclusions which can be propounded with reference to the facts observed from the parallel of 45° to the Arctic ocean.

* G. M. Dawson, Superficial Geology of British Columbia: Quart. Jour. Geol. Soc., vol. 34, 1878, p. 89, et seq.; ibid, vol. 37, 1881, p. 272, et seq.

One other point remains to be illustrated with reference to the local origin of the vegetable remains. Where these consist of trunks and branches and are contained in the bowlder-bearing beds, they may, like those found under similar conditions in the arctic, be drift-wood, derived from great distances and in a condition of partial submergence of the continent. The facility for such distribution must, in the Pleistocene age, have been greater than it now is in the arctic, where there is, according to the testimony of voyagers, not only a great quantity of such material on the shore, but mixed with clay and bowlders at some distance inland. There is reason to believe that throughout Canada such drift-wood may be found here and there in both the upper and lower bowlder deposits.

Where, however, we have leaves and other perishable parts, and especially where there are peat beds and peaty soils, or where the vegetable remains are associated with fresh-water shells, the case is different. We have in these circumstances evidence of the local flora, and cannot doubt that the climate must have been sufficiently mild to permit the growth *in situ* of the plants whose remains are found. So far as we know at present, evidence of this kind applies, *first*, to the land surfaces anterior to the earlier bowlder deposit; *secondly*, to the swamps and uplands of the *Leda* clay and "interglacial" period; and, *thirdly*, to the early modern time succeeding the upper bowlder drift. The plants specially referred to in the following notes are, so far as known, those of the second of the above periods.

In conclusion, it is deserving of notice that the plants indicated in Professor Penhallow's lists are not an arctic assemblage, but rather a part of the cold temperate flora. They scarcely indicate so much refrigeration as that evidenced by the plants from British interglacial beds as described by Carruthers.* Further, as the species referred to are either local or drifted by streams from the north, it follows that the arctic flora must have existed to the north of the Canadian localities referred to. This accords with the fact proved by arctic explorers and the officers of the Geological Survey of Canada,† that in the glacial period striation and driftage of bowlders point to drift toward the arctic basin as well as toward the south. Thus, when these plants flourished in Canada, there must have been open water and a land flora in the arctic basin—conditions, of course, altogether incompatible with the existence of a polar ice-cap, though not inconsistent with the occurrence of glaciers in the more elevated districts or those cooled by the cold arctic currents. That the climate was colder, locally at least, in the period of the bowlder clay need not be doubted, but there is reason to believe that the general difference of temperature in the so-called interglacial period as compared with that of the bowlder clay has been greatly exaggerated.

* British Association Report, 1886, pp. 683; Dawson, "Geological History of Plants," 1888, pp. 225.

† G. M. Dawson, Geology of Northern Part of Canada, Report Geological Survey of Canada, 1887, p. 51, et seq.

II. *NOTES ON THE PLEISTOCENE PLANTS. BY D. P. PENHALLOW.*

The Pleistocene plants submitted to the author by Sir William Dawson and described in this paper, are chiefly from collections made by Dr. G. M. Dawson and Mr. J. B. Tyrrell, of the Geological Survey of Canada, and by Mr. J. Townsend, with specimens from different localities in the collections of Sir William Dawson, now in the Peter Redpath Museum of McGill University. A few are donations from Messrs. Worthen and Andrews from localities in the United States. These latter will be but briefly referred to, as the precise formation in which they occurred is not wholly free from doubt. Some of the material is of recent collection and until now undescribed. Other specimens were collected at least twenty years ago, and have already been more or less fully described* by Sir William Dawson. These I have submitted to examination for the purpose of verification, and now present in the following statement.

Annotated List of Canadian Plants.

TAXUS BACCATA, L.

The material representing this species was embraced in several slides, which I have designated by the numbers 1, 2, and 3, and by specimens of wood, which have also been numbered as follows:

No. 1. A section taken from a specimen from the Don river, Toronto. The structure is fairly well preserved, and shows the characteristic structure of *Taxus*.

No. 2. A longitudinal section of a specimen from Solsgirth, Manitoba, taken from the bowlder clay of a well at a depth of 135 feet.† The structure is well preserved, and the taxine characters of the wood are more clearly recognizable than in the preceding.

No. 3. Transverse section of a specimen also from Solsgirth, Manitoba. The section is cut diagonally, but as the structure is well preserved the characters are recognizable.

No. 4. A fragment of wood about one and one-half inches square, much compressed, and evidently the nodal portion of a small stem or branch. It was collected in 1887 by Mr. Tyrrell from the till formation of the Solsgirth well. It is readily softened in hot potash, but the whole structure is badly decayed and much distorted by compression. It everywhere shows coniferous markings, and where more fully preserved the structure of *Taxus* is plainly seen.

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*Can. Nat., Vol. II, 1857. p. 522; ibid., New Ser., Vol. III, 1870, p. 69; ibid., Vol. VI, 1871, p. 403.
†Trans. Roy. Soc. Can., Vol. IV, Pt. IV, 1886, p. 92.

No. 5. A specimen from the same locality by the same collector as above. It represents the broken end of a branch or small trunk about two inches in diameter. The form has suffered little change, and to the surface there still adhere small pieces of bark. The preservation of this specimen is so distinct from that of the others as to lead to the supposition, upon external examination, that it is a distinct kind of wood. It shows everywhere the effects of advanced decay, and it is also impregnated to some extent with silica. This condition of preservation rendered it extremely difficult to obtain longitudinal sections and impossible to get transverse sections. The former, which were secured in small fragments, were sufficient to place the coniferous character of the wood beyond dispute, and in places the spiral structure of *Taxus* was evident.

In a recent communication, Mr. Tyrrell stated that specimen No. 4 was obtained from a depth of 360 feet, and that No. 5 was exceedingly soft when found; but the precise depth at which it occurred is not known, though probably one of those depths at which wood occurred as mentioned in the report of Dr. G. M. Dawson.*

No. 6. Embraces two small fragments of wood about one-half inch square and strongly compressed; also three slides of the same. This material was collected by Mr. J. B. Tyrrell, in 1887, from the drift of Rolling river, two miles above Heart hill, Manitoba.

Fresh sections were cut, but the material was in such an advanced state of decay that the treatment with potash had to be applied cautiously, and microscopical examination showed that it had also resulted in the removal of a large part of the structure of the cell walls, of which, in most cases, only the primary cell wall remained. The characteristic markings of coniferous wood were thus in many cases wholly removed, but in places, where the action of decay was more limited, the markings peculiar to *Taxus* were observed.

7. Another specimen of *Taxus* from peat below bowlder clay on the River Inhabitants, Cape Breton, obtained by Sir William Dawson, and now in the collection of the Peter Redpath Museum, has been examined. It is a fragment of a branch about three-fourths of an inch in diameter and six inches long, much flattened by pressure. The structure shows it to be a *Taxus*, but presenting some aspects different from those of our modern species. These may have resulted from local conditions, since the wood rings show it to have grown very slowly, as if in a situation unfavorable to it. A more critical examination will be made later; for the present I refer it to *T. baccata* provisionally.

The modern Canadian species of *Taxus* are *T. brevifolia*, Nutt., and *T. baccata*, L., var. *Canadensis*, Gray. To the first, none of the specimens described

* Ibid.

can be referred, as they differ from it in a somewhat marked manner; but they do approach the latter species, to which I shall therefore refer them. *Taxus baccata* is now found extending from Newfoundland, Anticosti, and Nova Scotia, where it is abundant, through New Brunswick, Quebec, and Ontario. On the shore of Lake Huron it often forms impenetrable thickets. Passing to the west it still continues abundant north of Lake Superior, and at least to Lake Winnipeg, according to Macoun.*

ASIMINA TRILOBA, DUNAL.

The specimen of this fossil is from the Pleistocene of the Don river, Toronto, having been collected in 1887, by Mr. J. Townsend, from a cut at Jail hill, at a depth of sixty-six feet below the surface, and from below the Erie clay of that locality. It is about six inches long by two wide, and evidently was derived from a tree of small diameter, as indicated by the curvature of the growth rings. In its general aspect it bears a very strong resemblance to the wood of our modern *Asimina triloba*, with which it is also closely comparable in its minute structure. It presents certain differences in detail—*e. g.*, the development of the thyloses is much more strongly marked, the wood cells are of smaller diameter, and there are also certain differences in the markings of the vessels. Alteration under the conditions established by its long burial may account for some of these, and perhaps none of them are sufficient to mark a distinct species. I would therefore assign it for the present to our modern species of *A. triloba*.

The material was well preserved, and all the details of structure could be distinguished without difficulty. By boiling in potash, sections were as readily cut as if taken from fresh material.

At present *Asimina triloba*, the only species found within Canadian limits, occurs in Ontario, at Queenstown heights. It is very abundant at Point Pelée and in the townships bordering on Lake Erie between that point and Amherstburg. Doubtless it is not rare along Lake Erie, though not yet reported (Macoun).

ULMUS RACEMOSA, THOMAS.

This fossil is represented by two specimens, numbered 2 and 3.

No. 2 is twelve by six inches, and evidently derived from a somewhat large tree. It was obtained in 1887 from a cutting on the Don river, from beneath the Erie clay, at a depth of sixty-six feet from the surface, and associated with the previously described species.

The material is fairly well preserved, though showing the effects of decay in the exfoliation of the growth layers; while under the microscope the dis-

* The occurrence of *Taxus baccata* in the Pleistocene deposits of Manitoba has been noticed by Dr. G. M. Dawson in the Transactions of the Royal Society of Canada, vol. IV, part IV, 1886, p. 92.

torted structure shows the effect of compression, which has turned all the medullary rays off obliquely. This, together with compression of the vessels and wood parenchyma, has resulted in the groups of wood cells being distributed in the form of diamond-shaped masses, which are at first very misleading as to the true character of the wood. In consequence of these alterations it was impossible to cut truly radial or tangential sections. The material submits readily to the action of potash, whereby sections are easily cut.

No. 3 was obtained from the same locality as the preceding, and about two feet below a band of sand containing leaves. It appears to be one side of the stump of a small tree, as it shows the spreading base usually found at the point where the roots separate. It is four inches long by three and one-half wide at the widest part. Portions boiled in caustic potash gave very fine sections, and showed the structure to be not only well preserved, but also largely free from the effects of compression, so that the distribution of the tissues could be readily determined. The compactness of the structure, as well as the very small, thick-walled cells, shows it to have been a very hard wood. Both of these specimens (2 and 3) are identical. They present the unmistakable structure of the genus *Ulmus*, of which *U. fulva*, Michx., *U. americana*, L., and *U. racemosa* are at present found in Canada.

A close comparison with these different species shows that the fossils so nearly approach *U. racemosa* as to admit of referring them to that species.

Within Canadian limits, *U. racemosa* is rather rare in the eastern townships, Quebec, extending thence westward throughout Ontario, in the limestone areas. It seems to be confined to dry, gravelly soils, and is usually associated with sugar maple in such localities. It was formerly very common, according to Macoun.

GEN. AND SP. UND.

Three sections of wood—one transverse and two radial—from the interglacial at Solsgirth, Manitoba, collected by Dr. G. M. Dawson. The plant was evidently exogenous. It was either very soft in its original state, or, as seems more probable, the sections present the remnants of decayed tissue. At all events, the state of preservation was such as to prevent correct determination.

THUYA OCCIDENTALIS, L.

A small fragment of wood, about one-fourth of an inch in diameter and an inch and one-quarter long, from the *Leda* clays, Montreal (collection of Sir William Dawson). This species extends from New England, throughout Quebec and Ontario, northward to within twenty miles of Lake Mistassini, to James's bay and in the neighborhood of Moose factory. The northern

limit crosses the Albany at some distance from the sea, extending westward to a point about seventy-five miles southwest of Trout lake, thence southward to Lake Winnipeg and the United States boundary. It is one of the trees most likely to be found in this formation. This species has been recognized by Sir William Dawson in the drift of the Roseau river, Manitoba, and of Montreal (*Leda* clay) and the Ottawa river.*

ELODEA CANADENSIS (?), MICHX.

A specimen of soft stone bearing the impress of a small branching plant and the carbonized remains of another of the same kind. This was from the collection of Mr. Tyrrell, made in 1887, and obtained from Rolling river, Manitoba, two miles above Heart hill. A slide of the same plant and from the same locality, from Dr. G. M. Dawson, shows the plant to have been herbaceous, but with a distinctly vascular axis, the wood cells of which are thin walled and with rather blunt terminations. This vascular structure is surrounded on all sides by a distinctly parenchymatous structure. Associated with this plant are many diatomaceous remains belonging to fresh-water species, among which I have recognized *Navicula lata*, *N. legumen*, *Encyonema prostratum*, *Denticula lauta*, and various species of *Licmophora* (?) and *Cocconeis*. It is therefore clear that the plant is not a seaweed. The distinctly branching habit and the structure suggest *Elodea*, although the state of preservation is not such as to render exact comparison possible. I therefore refer it provisionally to our common Canadian species, *E. canadensis*, which is everywhere found in fresh water.

VALLISNERIA (?).

Several fragments of the same earthy material as above, bearing each a small fragment of a leaf. This is in each case linear, with a well-rounded apex, and usually about 2.5 mm. wide. The epidermis is apparent under a pocket lens. In fact the remains appear to consist wholly of the two epidermal layers, which may be separated readily. Under the microscope the epidermal cells are found to be well preserved. No stomata have been found, and this, together with the presence of fresh-water diatoms, would indicate that it must have been a submerged, aquatic plant. The structure strongly reminds one of *Vallisneria*, to which I shall provisionally refer it. This plant is everywhere common in fresh water, and is very likely to have occurred in such a locality as that from which the fossil was obtained.

CAREX MAGELLANICA, LAMARCK.

The Green's creek nodules contain an abundance of leaves, evidently of grasses and sedges. In one nodule from the Miller collection and in two

*Can. Nat., New Ser., Vol. III, 1868, p. 72; Report on 49th Parallel, 1875, p. 214; Notes on Post-Pliocene, op. cit., 1871, p. 404.

belonging to the collection of Mr. John Stewart, of Ottawa, there were found portions of old spikes devoid of seeds, but with the persistent glumes widely spread, evidently the remains of a *Carex*. In other nodules belonging to the Miller collection in the Peter Redpath Museum, there were found complete spikes containing the seeds, apparently the same as the preceding. In both cases the resemblance to *Carex magellanica* is so marked that I have ventured to refer them to it.

At present this species is found in peat bogs from Newfoundland to Vancouver.

BRASENIA PELTATA, PURSH.

This is evidently an undeveloped leaf, of which only one-half, embracing the stump of the petiole, is represented. The form and, to some extent, the venation show its probable relation to the species above named.

Brasenia peltata occurs at Rocky lake, Nova Scotia; Grand lake, New Brunswick; Point St. Charles, Montreal; River Range; and is abundant throughout the northern counties of Ontario, and about Rainy lake and Lake of the Woods, according to Macoun.

LARIX AMERICANA, MICHX.

Several small branches about three inches or less in length and from one-third to three-fourths of an inch in diameter, from the Geological Survey of Canada, through Sir William Dawson. They were collected by Mr. J. C. Weston from the *Leda* clays in Peel's clay pit, Montreal. The structure is fairly well preserved and recognisable without difficulty.

In its present distribution, *Larix americana* is common in all swampy ground from Newfoundland and Labrador, through the eastern provinces, to the foot of the Rocky Mountains; northward to latitude 65°.

POPULUS GRANDIDENTATA, MICHX.

Base of a small stem or branch about two and one-half inches long. The structure is quite well preserved and readily comparable with the above species. It was obtained from the *Leda* clays of Montreal by Mr. J. C. Weston, and transmitted to me from the Geological Survey of Canada by Sir William Dawson. Also in nodules from Green's creek, Ottawa, now in the collection of Mr. J. Stewart, small branches of this same species were found.

Populus grandidentata is common in Nova Scotia and New Brunswick, as also throughout Quebec and Ontario.

POTAMOGETON RUTILANS (?), WOLFGANG.

A single specimen in a Green's creek nodule from the collection of Mr. J. Stewart. It embraces the stem and several leaves.

This species is at present known only near Red Rock, Lake Superior, and on Twin island, James's bay; in marshes on Anticosti; and at the mouth of the Nipigon river (Macoun). It would therefore appear probable that it was more abundant in the past than at present.

EQUISETUM LIMOSUM (?), L.

E. SYLVATICUM (?), L.

Fragments of plants with lateral members in whorls were frequently met with and, although not satisfactorily referable to any modern genus, presented the closest resemblance to the two species of *Equisetum* above named, to which they are provisionally referred.

MENYANTHES TRIFOLIATA, L.

A specimen of the *Leda* clays from Montreal, now in the Peter Redpath Museum, shows the remains of a plant of which only the basal portion is preserved. This consists of a central axis from which rather stout lateral members are developed at right angles, and from which in turn are produced numerous fine roots. The specimens are of small diameter, but from their evidently shrunken character must represent the remains of plants approaching one-quarter of an inch in diameter. Although not clearly referable to any existing species, the resemblance to the stem of *Menyanthes trifoliata* is very striking, and in all probability it represents a similar underground stem with its roots developed at right angles to the axis of growth. The absence of leaves renders a more accurate determination at present impossible.

Description of New Species.

ACER PLEISTOCENICUM, SP. NOV.

This fossil was recently obtained by Mr. Townsend from the Pleistocene of the Don river, Toronto, and was purchased by Sir Willam Dawson with other specimens and presented to the Peter Redpath Museum. Though not perfect as to form, the leaf is beautifully cast in an argillaceous nodule, and shows several details of venation quite perfectly. A drawing, giving a restoration of the leaf, is herewith presented. From this it will be seen that the left half of the blade is nearly intact, while of the right half only about two-thirds remain, the lobes being entirely cut off by fracture of the matrix.

The leaf is evidently that of a maple, although of a type quite distinct from any of our existing forms. As will appear from the figure, the general

form and venation suggest *Platanus*, and a specific name indicating this resemblance would be appropriate, were not some of the existing species already so distinguished. It is to be regretted that this is the only specimen so far found in a fairly complete condition, since it is unsatisfactory to base conclusions upon a single specimen where there is opportunity for variation.

The modern maples with which the fossil is most nearly comparable are *Acer rubrum* and *A. platanoides*. In its general outline, the fossil is broadly

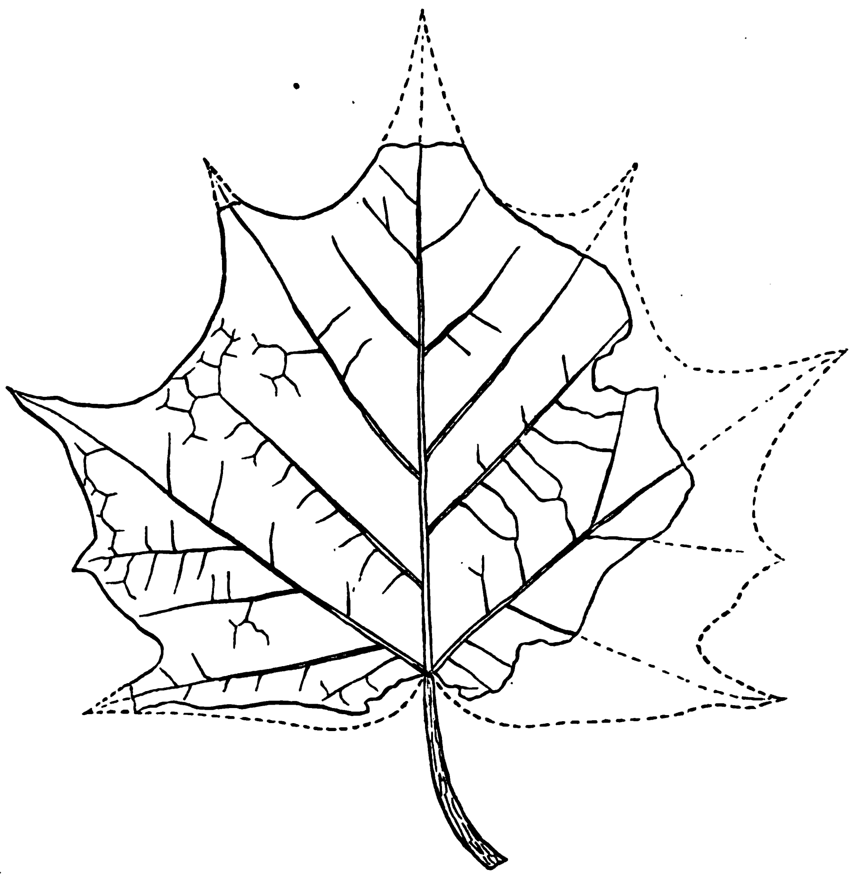

FIGURE 1.—*Acer pleistocenicum*.

ovate and, if we follow the same rule as in other maple leaves in respect to the number of lobes being determined by the palmate distribution of the principal veins, three lobed; but the terminal lobe has two prominent lateral lobes, while the others have each a small basal lobe, all somewhat strongly defined and making the leaf appear seven lobed. The lobes are all very

acute. The margin is entire with the exception of two teeth, one on each side and situated midway between each lateral lobe and its inferior lobe. The sinuses are open, shallow, and well rounded. In many of these respects it approaches *Acer platanoides*, from which it differs in its much broader terminal lobe and in the broader and more shallow sinuses.

The venation is most nearly comparable with that of *Acer rubrum*, where, as in the fossil, only two veins are arranged palmately with the midrib, and from these branch smaller veins which run to the small basal lobes.

The second and third veins, lateral to the midrib, run to the principal sinus of each side, where they terminate near the margin by repeated dichotomous branching. This, however, is common to several of the modern maples. The finer venation is essentially the same as in our modern maples.

It would appear from this that the fossil cannot be properly referred to any of our existing species, and it appears desirable to give it a distinctive name. I therefore propose to call it *Acer pleistocenicum*, as properly descriptive.

REVISION OF PREVIOUSLY RECORDED PLEISTOCENE PLANTS.

The following specimens from Green's creek, as referred to by Sir William Dawson in the preceding pages, have already been partially determined by him and published in 1868, with figures of some of the species.* The present revision shows a few changes and includes a few specimens not originally noted, and which have been acquired by the Redpath Museum from the collection of the late Mr. J. G. Miller since the publication of Sir William Dawson's paper.

DROSERA ROTUNDIFOLIA, L.

A nodule containing a single specimen of what appears to be a leaf of this plant, showing marginal projections and surface markings bearing somewhat close resemblance to the glandular hairs. Its association with the fertile spike of an *Equisetum* shows it to have been a habitant of moist places such as are usually favorable to its abundant development. It is a species very commonly distributed throughout Canada.

ACER SACCHARINUM, WANG.

A basal fragment of a leaf in a nodule. This specimen was originally designated † as *A. montanum*, Ait. (*A. spicatum*, Lamx). The only data on which a determination is possible are to be found in the angles at which the veins separate and in the number and distribution of such veins. With reference to the first, it is to be observed that the angles of the veins with

* Can. Nat., New Ser, Vol. III, p. 70 et seq.
† Ibid.

the midrib vary considerably in the same species, so that this cannot be regarded as a character of more than approximate value. The number and distribution of the veins offers a somewhat more reliable guide, since there is a constancy in this respect which is of value. The majority of our maples fall in one of two types. In the first case, four principal veins are arranged palmately with the midrib, and directly extend to as many distinct lobes of the leaf, the first pair usually extending horizontally or obliquely downward to the basal lobes. To this type can be referred such species as *Acer platanoides* and *A. saccharinum*. In the second case, only two principal veins are directly and palmately arranged with the midrib, while from each of them there springs a subordinate vein at a short distance from the base, which then extends to the corresponding basal lobe. Examples of this type are to be seen in *Acer rubrum* and *A. dasycarpum*, as well as in the fossil *A. plestocenicum*.

In the fossil under consideration there are four distinct veins palmately arranged with the midrib, two of which are large, and the other two running to the basal lobes. It will thus be seen that comparison with *Acer montanum* cannot be considered. A close comparison with the leaves of the first group shows that it approaches most nearly to *Acer saccharinum* in all those characters represented.

The present distribution of *A. saccharinum* covers a wide range throughout Canada, from Newfoundland and Nova Scotia to the western extremity of Lake Superior, and northward to Lake St. John and to the Long portage on the Michipicoten river.

POTENTILLA ANSERINA, L.

Two specimens and their reverses in nodules previously determined* as *Potentilla canadensis* and *P. norvegica*, and also a specimen and its reverse in Mr. Miller's collection in the Peter Redpath Museum. The leaves only are represented, but the venation is so distinctly preserved, as well as the general form and margin, as to leave little doubt as to their true character, although in one case they are so grouped by crushing as to bear a certain resemblance to the leaf of *P. canadensis*. In this species the veins run directly from the midrib of the leaflet to both teeth and sinuses. In *P. norvegica* the veins run to the teeth, taking a direction which tends to become parallel with the margin, and while the vein itself extends into a tooth it gives off a lateral which penetrates the tooth below, so that there are in reality twice as many teeth as veins. The fossils, which in this respect as in others are all similar, show the veins running directly to every tooth, veins and teeth being equal in number.

In this respect, as well as in the form of the leaflet, the shape and apices

* Can. Nat., New Ser., Vol. III, 1868, p. 70.

of the teeth and their inclination to the midrib, the fossil corresponds most closely with *P. anserina*, to which I therefore refer them. At present this species is very abundant along the eastern coast and on the margins of rivers and lakes throughout the interior and as far north as the Arctic sea.

GAYLUSSACIA RESINOSA, TORR. AND GRAY.

A well-preserved leaf in a nodule. This shows the form of the leaf, and the resinous dots are so perfectly seen as to render it readily determinable. This species is now found in rocky or sandy woodlands and in bogs, from Newfoundland and Nova Scotia to the Saskatchewan.

POPULUS BALSAMIFERA, L.

The material representing this species is embraced in leaves and fragments of branches contained in nodules. The former are in most cases well preserved and admit of easy identification. As noted in the original description, however, the leaves are all small, and assuming them to be mature this would indicate a cold climate or very exposed situations. At present *P. balsamifera* is of very wide distribution throughout Canada, extending northward to the mouth of the Mackenzie river, where it attains large size, and is an important source of fuel (Macoun).

POTAMOGETON PERFOLIATUS, L.

Portions of leaves and seeds in nodules. The venation is beautifully distinct, and it is without much doubt referable to the species named. This is one of our most common water weeds, being found everywhere in the streams of the northern United States and Canada.

POTAMOGETON PUSILLUS, L.

This is one of the most abundant plants contained in the nodules from Green's creek. The specimens all show a branching plant with narrow leaves. This species is now common in slow streams and ditches almost everywhere.

EQUISETUM SCIRPOIDES, MICHX.

Common in the nodules from Green's creek, and associated with *Potentilla anserina*. This is a widely distributed species, and would naturally occur among such plants as are found at the above locality.

There is also another nodule containing a portion of a stem cut longitudinally. It has the appearance of an *Equisetum*, and may possibly be referred to one of the larger species, such as *E. palustre* or *E. limosum*.

ORYZOPSIS ASPERIFOLIA, MICHX.

A fragment of a leaf and stem in a nodule, showing features which make them correspond closely with *Oryzopsis asperifolia*, and to which I therefore

refer them. This species is a widely extended one, being found from Newfoundland to the Rocky Mountains.

FUCUS.

A specimen of a seaweed in a nodule, evidently a *Fucus*. It is not strictly comparable with any of our modern species, and until more material is obtained it seems best not to assign any specific name to it, although *digitatus* would appear to be appropriate.

FONTINALIS.

Fragments of mosses are common in the nodules from Green's creek. These appear to be chiefly of the genus *Fontinalis*, or one nearly related to it.

In addition to the above there were also found in the Green's creek nodules various seeds. These require some further examination.

BROMUS CILIATUS, L.

A fragment of a leaf which shows a venation closely corresponding to *Bromus ciliatus*, to which I would for the present refer it. This is a very common species in thickets and damp places throughout Canada. The specimen was collected by Mr. J. G. Miller from Green's creek.

GEN. AND SP. UND.

Among the specimens sent us by Dr. G. M. Dawson was a seed collected by Mr. J. B. Tyrrell, in 1887, from the Rolling river, Manitoba, two miles above Heart hill. The form and size seem to indicate that it is the seed of a Conifer.

LIGNITES.

A sample of lignite or indurated peat, collected by Dr. G. M. Dawson from the interglacial deposits of Belly river, was presented in the form of balsam mounts and loose material, all of which had been treated with potash, nitric acid, sulphuric acid, or chromic acid. In all cases the material was found to be very finely divided, none of the fragments being of sufficient size to make reference to particular orders or genera possible. It was, however, quite possible to recognize fragments of sclerenchyma tissue, fragments of wood cells, spores of ferns, and what appeared to be the extine of pollen grains. These latter, together with the few spores, constituted the bulk of the recognizable material. There were also to be observed fragments of epidermis, apparently of three different kinds, and in one instance two stomata were found, though imperfectly preserved. The impression gained from a careful examination of a large amount of material is that the

peat consists of the remains of ferns and herbaceous or semi-woody plants. No more definite statement can be made until other material is examined.

A specimen of lignite from Cape Breton was also submitted to examination. This material was described some years since by Sir William Dawson,* and is also noted in the preceding pages of this paper by him. Boiled out in potash, there have been found in it an abundance of fungus hyphæ, the extine of coniferous pollen, bast cells, sclerenchyma tissue of ferns, epidermis apparently of ferns, wood cells showing a portion of a medullary ray, and fragments of endogenous stems. This is all that could be found after searching through a large amount of material, and the conclusion was reached that the lignite represents the remains of ferns and grasses with fragments of woody plants, possibly from a more elevated and less wet locality.

Woods from Illinois.

In addition to the specimens above described, I have also examined three slides of coniferous wood from Bloomington, Illinois.† These were found at depths of 100 and 107 feet from the surface, and were said to be at the bottom of the bowlder clay. They were provisionally designated as *Abies*, but a careful comparison with existing species of *Abies*, *Tsuga*, and *Picea* has led me to refer them to *Picea alba*, *Link*.

There were also two slides of *Taxus baccata* from the same locality, at a depth of 107 feet.

Synopsis.

The following summary of species and their distribution may be given:

1. *Asimina triloba*, Dunal. Don river, Toronto (Townsend).
2. *Brasenia peltata*, Pursh. Green's creek nodules (Miller).
3. *Drosera rotundifolia*, L. Green's creek, Ottawa (J. W. Dawson).
4. *Acer saccharinum*, Wang. Green's creek, Ottawa (J. W. Dawson).‡
5. *Acer pleistocenicum*, sp. nov. Don river, Toronto (Townsend).
6. *Potentilla anserina*, L.
   Green's creek, Ottawa (J. W. Dawson and Miller).
7. *Gaylussacia resinosa*, Torr. and Gray.
   Green's creek, Ottawa (J. W. Dawson).
8. *Menyanthes trifoliata*, L. *Leda* clays, Montreal.‡
9. *Ulmus racemosa*, Thomas. Don river, Toronto (Townsend).
10. *Populus balsamifera*, L. Green's creek, Ottawa (J. W. Dawson).‡

* Acadian Geology, 1878, p. 63.
† Presented to Sir William Dawson by Dr. Andrews and Professor Worthen, and now in the Peter Redpath Museum.
‡ Collection of Sir William Dawson in Peter Redpath Museum.

11. *Populus grandidentata*, Michx.
 Leda clays, Montreal (Weston).
 Green's creek nodules (Stewart).
12. *Picea alba*, Link. Bloomington, Ill. (Andrews).
13. *Larix americana*, Michx. *Leda* clays, Montreal (Weston).
14. *Thuya occidentalis*, L.
 Leda clays, Montreal (Sir William Dawson).
 Leda river, Manitoba (Dr. G. M. Dawson).
 Marietta, Ohio (Newberry).
15. *Taxus baccata*, L.
 Don river, Toronto (Townsend).
 Solsgirth, Manitoba (G. M. Dawson and Tyrrell).
 Rolling river, Manitoba (Tyrrell).
 Cape Breton (Sir William Dawson).
 Bloomington, Ill. (Andrews).
16. *Potamogeton perfoliatus*, L. Green's creek, Ottawa (J. W. Dawson).
17. *Potamogeton pusillus*, L. Green's creek, Ottawa (J. W. Dawson).
18. *Potamogeton rutilans* (?), Wolfgang. Green's creek nodule (Stewart).
19. *Elodea canadensis* (?), Michx. Rolling river, Manitoba (Tyrrell).
20. *Vallisneria* (?). Rolling river, Manitoba (Tyrrell).
21. *Carex magellanica*, Lamarck.
 Green's creek nodules, Ottawa (Miller and Stewart).
22. *Oryzopsis asperifolia*, Michx. Green's creek, Ottawa (J. W. Dawson).
23. *Bromus ciliatus* (?), L. Green's creek, Ottawa (Miller).
24. *Equisetum sylvaticum* (?), L. Green's creek nodules (Stewart).
25. *Equisetum limosum* (?), L. Green's creek nodules (Stewart).
26. *Equisetum scirpoides*, Michx. Green's creek, Ottawa (J. W. Dawson).
27. *Fontinalis* (?), sp. Green's creek, Ottawa (J. W. Dawson).
28. *Fucus*, sp. Green's creek, Ottawa (J. W. Dawson).
29. *Navicula lata*. Rolling river, Manitoba.
30. *Encyonema prostratum*. Rolling river, Manitoba.
31. *Denticula lauta*. Rolling river, Manitoba.
32. *Licmophora* (?). Rolling river, Manitoba.
33. *Cocconeis*. Rolling river, Manitoba.

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THE VALUE OF THE TERM "HUDSON RIVER GROUP" IN GEOLOGIC NOMENCLATURE.

BY CHARLES D. WALCOTT.

(*Read before the Society December* 27, 1889.)

CONTENTS.

INTRODUCTION.

From the windows of the building in which we are assembled we can look out over the broad expanse of the river* upon which Henry Hudson sailed two hundred and eighty years ago (1609). It was afterward christened "Hudson" by the English, and it has retained this name with the unanimous consent of the geographers of the centuries since. It seems well to-day to consider the place of the same name in the geologic nomenclature of America, as its retention has been threatened by the conclusions of various geologists, some of whom have, while others have not, studied the rocks of the Hudson valley.

The question before us is, What is the value of the term "Hudson River," in the light of the latest geologic research?

HISTORICAL AND DESCRIPTIVE NOTES.

The rocks of the valley of the Hudson were described in a general way by Amos Eaton, in a series of publications extending from 1817 to 1832.†

* Discovered by Verrazzani in 1524. Named "River of the Mountains" by Hudson in 1609, and called "Mauritius" in honor of Prince Maurice of Nassau by Englishmen a short time after. About 1692 it became generally known as the North River.

† Index to the Geology of the Northern States, 1818, 2d ed., 1820; Geol. and Agric. Survey Rensselaer county, 1822; Geol. Text Book, 1830, 2d ed., 1832.

In 1820,* Rev. Chester Dewey published an account of a section extending from the Taconic mountains to the Hudson river at Troy. His observations and those of Eaton are too general in character to be of more than historical interest at present.

With the advent of the Geological Survey of New York, in 1836, systematic work was inaugurated and a classification developed which gave a great impetus to geologic research in America.

The first geologic district embraced the valley of the Hudson, and was placed in charge of Dr. W. W. Mather, who, in 1840, proposed the name "Hudson River Slate group." He says, in speaking of the rocks in the valley of the Hudson:

> The lowest in the series is the Hudson River Slate group, consisting of slates, shales, and grits, with interstratified limestones, all of which occur under various modifications. This group is overlaid unconformably in many places by the various rock formations of more recent origin. The next in order of superposition in the district under examination * * * is the Shawangunk grits. * * * The next in order is the Helderberg group; * * * and the Catskill Mountain group terminates the series of indurated rocks in the First district.†

From Kingston the Hudson River group ranges along the right or western bank of the Hudson river to Albany, underlying the superincumbent rocks unconformably, with *few* exceptions. A few fossil shells or impressions of shells were found in the sandy beds, and some graptolites in the black shales underlying the Shawangunk grits. In the final report of the first district, Dr. Mather changed the name Hudson River Slate group to Hudson River group.‡ The group as described may be classed by its structural relations into two divisions: (1) The approximately horizontal, unaltered strata, west of the line of disturbance in the valley of the Hudson. (2) The strata within the area of disturbance in the immediate vicinity of the river and to the east of the valley.§

The described sections of the undisturbed strata are portions of the highest part of the series, not far beneath the conformably superjacent Helderberg division. A measured section of 149 feet 4 inches at Schoharie kill, Schoharie county, shows an alternating series of shales with arenaceous layers or grits, some of which are calcareous. The thickness of the group could not be ascertained in any part of the Hudson and Champlain valleys, in consequence of the rocks having been deranged, upheaved and tilted; but in the valleys of Norman's kill, the Mohawk river and Schoharie kill, they are beautifully exposed to view. No actual measurement of these strata have been made, but it is estimated that they have a thickness of from 500 to 800 feet.|| The paleontologic evidence of the position of the strata consisted of

* Amer. Jour. Sci., vol. 2, 1820, pp. 246–249.
† Fourth Ann. Rep. Geol. Survey N. Y., 1840, p. 212.
‡ Geol. N. Y., Geol. First Geol. Dist., 1843, p. 367.
§ Loc. cit., pp. 369–389.
|| Loc. cit., p. 369.

a few fucoids and graptolites and a few specimens of testacea, none of which were designated by name.

Mr. Lardner Vanuxem accepted the term proposed by Dr. Mather, and described the Hudson River group as he found it in the Mohawk valley. It there rests upon the Utica slate throughout the district, and is next in order as to age. It is followed by the gray sandstone of Oswego, the rock which immediately succeeds it in the district where that rock exists.*

He further says:

> The name is adopted as being generally used in the Survey and as being more comprehensive than the one heretofore used; it is, however, objectionable from the difficulty in defining its limits along the region of the Hudson river.
>
> In Schoharie county the Hudson group is undisturbed and unaltered, and its maximum thickness is not less than 700 feet, but from the absence of the succeeding rock its precise position is not made known. Further west, in the same district, the whole series is complete and its position well defined.†

Mr. Vanuxem considered this group one of the universal ones, and that its two divisions are not coëxtensive: the lower one enters the first district along the Mohawk, and extends north by Rome through Lewis into Jefferson county; the upper division first appears in Oneida county, and from thence west and north it is an associate of the Frankfort slate or the lower division.

The sandstone-shales of Pulaski are fossiliferous portions of the second or upper division of the Hudson River group. As respects its fossil history, it will probably be subdivided, from the following facts: Fossils are rare in the lower part of the Frankfort slate, but are numerous where it joins the next series, the Pulaski shales. There is no essential difference between the fossils of this place, whether seen at the mill-race at Lee Centre or Whitall's quarry near Rome, at Halleck's spring in Hampton or in the gully near Utica or on the Cohoes near Waterford. In all these localities the group of shells which so peculiarly characterize the Pulaski shales is wanting, and others appear that had no previous existence in the district.‡ The upper division, or Pulaski shales, is stated to be characterized by *Cyrtolites ornatus*, *Ambonychia radiata*, *Modiolopsis modiolaris M. curva*, *M. ovata*; also *Orthonota parallella*, and other species not yet described.

Rome, New York, is given as the first locality west of the Hudson where the upper division is found. To the west of Rome, and north through Lewis county, it covers a large portion of the west side of the range of the Hudson River group. In Ohio and Indiana the upper division is seen with its fossils; the lower one has not yet been observed. It is there highly

* Geol. N. Y., Survey Third Geol. Dist., 1842, pp. 60–67.
† Loc. cit., pp. 60–61.
‡ Loc. cit., p. 64.

calcareous, and forms the upper part of the blue limestone of these two states.*

In January, 1842, Dr. Emmons described a series of shales in the Hudson River valley, and spoke of them as the Hudson River series or group. He says† that the whole extent of this group north and south is not well ascertained. It is known, however, to appear far northeast of Quebec, from whence it is traced south through Canada, Vermont and New York, and thence through Pennsylvania into the southern states. He does not correlate it with the Lorraine series of the northwestern part of New York.

Professor James Hall, in mentioning the Hudson River group in the report of the Fourth district, says: ‡

> "Where the strata are undisturbed a well marked line of division usually separates this group from the Utica slate; but along the Hudson river, and in other places where disturbance has prevailed, the two are not easily separable."

A list of fossils characteristic of the group is given, nearly all of which are found in the upper division but not in the Hudson River valley.

Professor Hall described the fossils of the Hudson River group in the first volume of the Paleontology of New York, 1847. The larger proportion of the species illustrated, with the exception of the graptolites and a few Lower Cambrian fossils from east of the Hudson, were obtained from the interior of the state of New York, southern Indiana and Ohio, and northern Wisconsin. At Waterford, on the Hudson, a few species were collected that served to connect the fauna of the Frankfort shale with that of the Hudson River shale; of this fauna the single species, *Ambonychia radiata*, indicates the fauna of the upper division of Vanuxem. The graptolites of the black shale on the west side of the Hudson river, as known under the present nomenclature, include the 13 genera and 29 species listed below, 6 genera and 9 species of which occur in the Utica shale of the Mohawk valley:

Rastrites barrandi, Hall.
Graptolithus (?) *laevis*, Hall.
Leptograptus subtenuis, Hall.
Amphigraptus divergens, Hall.
Stephanograptus gracilis, Hall.
" *surcularis*, Hall.
Didymograptus serratulus, Hall.
" *sagittarius*, Hall.
Clematograptus multifasciatus, Hall.

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* Loc. cit., p. 67.
† Geological Observations, Am. Mag., vol. 2, 1842, pp. 5–9.
‡ Geol. N. Y., Survey Fourth Geol. Dist., 1843, p. 30.

Dicellograptus divaricatus, Hall.
" *sextans*, Hall.
Dicranograptus ramosus, Hall.
" *furcatus*, Hall.
" *ramosus*, Hall.
Climacograptus parvus, Hall.
" *typicalis*, Hall.
" *scalaris*, Hall.
Diplograptus angustifolius, Hall.
" *marcidus*, Hall.
" *pristis*, Hall.
" *putillus*, Hall.
" *secalinus*, Eaton.
" *spinulosus*, Hall.
" *whitfieldi*, Hall.
" *mucronatus*, Hall.
Retiograptus barrandei, Hall.
" *geinitzianus*, Hall.
Thamnograptus capillaris, Hall.
" *typus*, Hall.

Of the preceding species, *Didymograptus serratulus*, Hall; *Dicellograptus divaricatus*, Hall; *Dicranograptus ramosus*, Hall; *Climacograptus bicornis*, Hall (doubtful); *Climacograptus typicalis*, Hall; *Climacograptus scalaris*, Hall; *Diplograptus pristis*, Hall; *Diplograptus putillus*, Hall, and *Diplograptus mucronatus*, Hall, occur in the Utica shale of the Mohawk valley, and *Diplograptus amplexicaule* of the Trenton limestone is found in the upper portion of the Lorraine section.

In the third volume of the Paleontology of New York, 1859, Professor Hall describes the Hudson River group, as known to him in the Mississippi valley and Canada. He says: *

"The group of strata known as the Hudson River group, which in its more extended signification may include all the beds from the Trenton limestone to the Shawangunk conglomerate, has afforded in New York but small additions to the number of fossils previously known in this formation."

In 1862 † Professor Hall concluded from the results of the extended study by the Canadian geologists, especially Sir William Logan, that the strata referred to the Hudson River group in the valley of the Hudson belonged to an older geologic epoch than that referred to the same group in western

* Loc cit., p. 14.
† Rep. Geol. Survey, Wisconsin, vol. 1, 1862, p. 47 (foot note).

New York and the Mississippi valley. He then proposed to drop the term Hudson River group. In explaining this note he says:*

"In the nomenclature proposed by the geologists of the State of New York for the several formations within the region of country explored by them the term *Hudson River group* was applied to a series of shales and argillaceous sandstones, with intercalated beds of limestone, which exist in great force along the Hudson river valley for a hundred miles above the Highlands.

"In this disturbed region the order of sequence does not appear to have been fully made out; but as the western extension of the Hudson-valley rocks along the Mohawk valley had been (as then supposed) traced to a junction with rocks known in the Annual Reports of the State Geologists by the names of *Utica slate*, *Frankfort slate*, *shales and sandstones of Pulaski*, and *Lorraine shales*, which rocks were known to rest on the Trenton limestone group, the single term of Hudson River group was proposed to embrace the entire series. In this the expressed object was to give the name from the locality which offered the most complete and extensive exhibition of the strata composing the group."

He stated that he was satisfied from the geologic relations of the great mass of these slaty rocks and from their contained organic remains that they were of older date, and that the fossils of newer age occurring in different localities have not been regarded as characterizing the formation; that the great mass of the Hudson River rocks in the typical localities are older than the Lorraine shales, the shales and sandstones of Pulaski, etc.; and that the term Hudson River group cannot properly be extended to these rocks, which, on the west side of the Hudson river, are separated from the Hudson River group proper by a fault not yet fully ascertained. He added:

"There can be no propriety in transferring the name Hudson River group from its typical locality and applying it to rocks which we now know to be of younger age, and which, when the sequence is complete, are separated from the Hudson River rocks by a great limestone formation.

"I have therefore dropped the term Hudson River group in its application to the rocks of Wisconsin, which are of the age of the Lorraine shales of New York and the Blue limestone group of Ohio."

Fifteen years after publishing the note in the Geology of Wisconsin (in 1862), Professor Hall reviewed the evidence on which his conclusions were based and decided that he had been in error in dropping the term Hudson River group. He says† that he accepted the determination made by the Geological Survey of Canada regarding the extension of the older rocks marked by the presence of a primordial fauna into the Hudson and Champlain valleys; also, at the time, the suggestion that the few fossils of the Trenton fauna of the Hudson River shales were contained in some outliers of insig-

* Loc. cit., p. 443.

† Note upon the History and Value of the Term Hudson River Group in American Geologic Nomenclature: Proc. Am. Assoc. Adv. Sci., vol. 26, 1877, pp. 259–265.

nificant extent embraced within the folds of the older rocks or resting upon the primordial beds of the fundamental rocks of the valley. The graptolites of the valley of the Hudson were referred to the primordial fauna by Mr. Billings, and the slates of the valley of the Hudson were claimed by Sir William Logan to belong to the primordial period, and not to the Lower Silurian as supposed by the New York state geologists.

From the data obtained subsequent to 1862, Professor Hall decided that the graptolites and all other fossils collected belonged to the second fauna—i. e., from the localities within the valley of the Hudson to which he refers. He says in conclusion:

"It [the term Hudson River group] has been accepted in geological nomenclature and it is incorporated in all our publications. We cannot, now, apply the term Cincinnati, or any other name to the shales and sandstones which exist in great development along the Hudson river, extending thence to the Mohawk and its tributaries, and traced in wide extension and highly fossiliferous character throughout the northwestern counties of New York." *

Dr. Ebenezer Emmons studied the strata between the Trenton limestone and the Medina sandstone in Jefferson county and the adjoining county of Oswego, New York, and proposed the name Lorraine for the rocks between the Utica shale and the Oswego sandstone. † He described with considerable detail the lithological characters of the Lorraine series, and figured the following fossils as characteristic of the upper portion: *Ambonychia radiata*, *Cyrtolites ornatus*, *Trinucleus concentricus*, *Strophomena alternata*, *Modiolopsis modiolaris*, *Orthoceras æqualis*, *Avicula demissa*, and *Orthis testudinaria*.

Reference is again made to the Lorraine series in a general description of the New York formations in 1847.‡ In speaking of the term Hudson River group, he says: §

"The only reason assigned for the name was that this subdivision presented certain peculiarities arising from a disturbance it had suffered along the Hudson river. The Hudson river region, however, presents no facilities for the examination of the upper part of the Lower Silurian; it is only at Lorraine or Pulaski, in the neighborhood of Rome, in New York, that this part of the series can be examined satisfactorily."

As geologist of the third district of New York, Mr. T. A. Conrad described and named in his first report on the district|| the "Gray Sandstones and Shales of Salmon River," or the series of alternating layers of gray sandstone and dark lead-colored, friable shales situated above the limestone of Trenton

* Loc. cit., p. 264.
† Geol. N. Y., Survey Second Geol. Dist., 1842, p. 119.
‡ Agric. N. Y., vol. 1, 1847, pp. 134, 135; and again in his American Geology, 1856; and in the little Manual of Geology of 1859–'60.
§ Am. Geol., vol. 1, pt. 2, 1856, p. 125.
|| 1837, p. 164.

Falls and beneath the red or variegated sandstone of Niagara river. He used the same nomenclature in his annual reports for 1838 and 1840; and in a table showing the classification of the New York rocks, published in 1840,* he used nearly the same scheme of classification except to place the Hudson slate, characterized by graptolites, beneath the Calciferous and Potsdam sandstones, thus anticipating the view subsequently published by Emmons, and in part adopted by Logan and followed by Hall in 1862. By priority of publication and completeness of definition, Conrad's term should have been accepted and used instead of Hudson River or Lorraine. Why it was not adopted by the New York state geologists remains unexplained.

In proposing and defining the term Nashville group,† Professor J. M. Safford stated that the line of demarkation between the Trenton limestone and the Hudson River rocks above was not clearly defined, owing to several species of the fossils of the Trenton running nearly to the top of the Hudson River rocks, and those of the Hudson River rocks extending down nearly to the base of the Trenton. In his table, the Nashville group is made to include the Hudson River and Utica slates, and the central and upper portions of the Trenton limestone. This view was republished in the first biennial report of the State survey in 1856. In the final report the classification was reviewed; ‡ all the Trenton beds were united under the term Trenton; and the *Orthis* bed was considered as the base of the Nashville formation on account of carrying the very characteristic species, *Ambonychia radiata* and *Cyrtolites ornatus*, also, *Rhynchonella modesta* and *R. capax*. Professor Safford says:

> "On such grounds we make the bed in question *Hudson River*, and fix the equivalency of the entire *Nashville formation*."

The Nashville formation is assigned a thickness of about 450 feet, and it is delimited below by the Trenton limestone and above by the Niagara limestone.

Under the title of "Hudson River group," Professor James Hall, describing the shales occurring between the Galena limestone and the Niagara limestone in Iowa, mentions certain shales on the Little Maquoketa river which were referred to the Hudson River group.§ It is stated that the section is scarcely more than twenty-five feet in thickness, and that on the opposite side of the river the entire thickness is probably less than 75 feet.

In the second geologic survey of Iowa || the classification adopted refers the rocks described as the Hudson River shales by Professor Hall to the

* Am. Jour. Sci., vol. 38, 1840, p. 90.
† Proc. Am. Assoc. Adv. Sci., vol. 7, 1853, p. 153.
‡ Geology of Tennessee, 1869, pp. 268–290.
§ Geol. Survey Iowa, vol. 1, pt. 1, 1858, p. 66.
|| Report Geol. Survey Iowa, vol. 1, 1870, by Charles A. White, p. 180.

Cincinnati group, under the name of Maquoketa shale. The formation is referred without reserve to the same geological series as the rocks at Cincinnati, Ohio. The author considered the section as a local or partial development of the Cincinnati series, and on that account proposed the name of Maquoketa. He was also influenced by the decision of Messrs. Meek and Worthen, who held that the Hudson River groups in Indiana, Ohio, Illinois, etc., were not equivalent to those of the Hudson series to which the name of Hudson River shales was first applied. A number of species of fossils were found that are also common to the Cincinnati formation.

In Professor S. Calvin's description of a deep well drilled at Washington, Iowa,* it is stated that at 702 feet a fine bluish or greenish shale, identical in all respects with the shales of the Hudson River group as seen in the gulch at and below Bellevue, Iowa, continues down to the depth of 793 feet, giving a thickness of 91 feet. This group of shales is plainly referable to the Hudson River shales of Hall or to the Maquoketa shales of White. In some "Notes on the Geology of Southeastern Iowa," C. H. Gordon † describes the strata passed through by a deep well at Keokuk. In this section the Maquoketa shale has a thickness of 63 feet.

During the field season of 1889, a collection of fossils was made from the typical Maquoketa locality by Professor Joseph F. James, of the U. S. Geological Survey. Of 41 species‡ collected and identified, all but seven are identical with those found in the fauna at Cincinnati. Stratigraphically, the Maquoketa shale is a diminished representative of the section at Cincinnati, and it is also identical in its lithologic and paleontologic characters.

* Notes on the formations passed through in the boring of the deep well at Washington, Iowa: Am. Geol., vol. 1, 1888, p. 29.

† Am. Geol., vol. 4, 1889, p. 237.

‡ *Monticulipora gracilis.*
" *lens.*
" *quadrata.*
Streptelasma corniculum.
Diplograptus amplexicaule.
" *putillus.*
Heterocrinus heterodactylus.
Porocrinus crassus.
Lichenocrinus crateriformis.
Fenestella, sp.
Paleschara maculata.
Lingulella cincinnatiensis.
Lingula coburgensis.
" *daphne.*
" *modesta.*
" *progne.*
" *whitfieldi.*
Schizocrania filosa.
Trematis, sp.
Leptaena sericea.
Strophomena alternata.
" *rhomboidalis*, var. *tenuistriata.*
Orthis biforata.
Orthis emacerata.
" *fissicosta.*
" *occidentalis.*
" *testudinaria.*
Zygospira modesta.
Pterinea demissa.
Cleidophorus neglectus.
Tellinomya obliqua.
Nucula fecunda.
Hyolithes parviusculus.
Coleolus (?), sp.
Conularia trentonensis.
Raphistoma micula (*subtilistriata*).
Tentaculites sterlingensis.
Murchisonia gracilis.
" *milleri.*
Pleurotomaria depauperata.
Orthoceras sociale.
Plumulites jamesi.
Beyrichia, sp.
Acidaspis crosotus.
Calymene callicephala.
Calymene mammillata.

Chronology of Names.

The chronologic arrangement of the names given to the series of rocks under consideration is as follows:

Salmon River; Conrad, 1836.
Hudson River; Mather, 1840.
Lorraine; Emmons, 1842.
Nashville; Safford, 1853.
Cincinnati; Meek and Worthen, 1866.
Maquoketa; White, 1870.

Discoveries of Recent Years.

The discovery of fossils other than graptolites in the dark shales or sandstones of the Hudson River group below Albany has been infrequent. Mr. T. Nelson Dale found a few species at Marlborough, about eight miles south of Poughkeepsie, in 1879, and Mr. Nelson H. Darton found a few Trenton-Hudson species twenty-one miles south of Newburgh, in 1885. On the east side of the Hudson, Mr. Dale discovered, in an argillaceous schist near Vassar College, an assemblage of fossils much like that reported by Mr. Darton in Orange county. The species range in the Trenton limestone and also in the upper part of the series in central New York. Mr. Dale says of them: *

"The occurrence of these fossils in these localities would then establish the fact that the gray slates and shales in the vicinity of Poughkeepsie, on both sides of the river, are fossiliferous, and that they very probably belong to the Hudson River group, as indicated by Mather in 1843; certainly, to some member of the Trenton period. These facts also speak in favor of the retention of the term Hudson River group, as advocated by Hall."

The most important discovery of fossils in the Hudson series, however, was that made by Mr. C. E. Beecher in the beds near the Dudley observatory, a short distance west of Albany.† The fauna included 26 species; and

* On the Age of the Slay-slates and Grits of Poughkeepsie: Am. Jour. Sci., 3d ser., vol. 17, 1879, p. 58.
† List of species of fossils from an exposure of the Utica slate and associated rocks within the limits of the city of Albany (36th Ann. Rep. N. Y. State Mus. Nat. Hist., 1883, p. 78):

Climacograptus bicornis.
Dicranograptus ramosus.
Diplograptus mucronatus.
Crinoid stems.
Trematis terminalis.
" *subtenta.*
Orthis testudinaria.
Hyolithes americanus (not of Billings).
" sp.?
Bellerophon bilobatus.
" *cancellatus.*
Murchisonia gracilis.
Endoceras proteiforme.
Ten undetermined species of lamellibranchiata.
Zygospira modesta.
Avicula trentonensis.
Cleidophorus planulatus.
Ambonychia undata.
Tellinomya dubia.
" *levata.*
Lyrodesma poststriatum.
Orthoceras bilineatum?
Cornulites flexuosus.
Plumulites, sp.
Triarthrus beckii.
Trinucleus concentricus.

it is, as a whole, characteristic of the upper portion of the Utica shale in the Mohawk valley and of the passage beds between the Utica shale zone and the lower portion of the Lorraine shales in the section at Lorraine, Jefferson county, New York.

Professor R. P. Whitfield concluded from his study of the graptolitic fauna at Norman's kill, near Albany, that the graptolite-bearing layers there are of the age of the Utica shale. He mentions four or five species of graptolites that are common to the Norman's kill fauna and the Utica shale in the valley of the Mohawk.*

When studying the strata on the east side of the Hudson valley, I was brought in direct contact with the disturbed strata that had been referred to the Hudson River group by Mather and Hall, to the Taconic system by Emmons, and to the Quebec group by Logan. For the purpose of obtaining a more intimate knowledge of the strata assigned to the Hudson River group west of the Hudson, I began by examining, during the field season of 1887, the contact of the Trenton limestone and Utica shale at the falls of the the Hudson, near Sandy Hill. This is the only point known to me where an undisturbed contact is shown between the Trenton limestone and the shales of the Hudson river valley. From this point the shales may be traced, with little interruption, to the neighborhood of Albany, where they are very much disturbed and stand at a high angle. In this vicinity the noted graptolite beds of Norman's kill occur; also the locality where Mr. Beecher discovered the upper fauna of the Utica shale zone. Following up Norman's kill, alternating shales and sandstones are passed over, all of which are highly inclined to the eastward. Crossing the line of disturbance, the shales and sandstones, of precisely the same lithologic character, are met with in a horizontal position. This series may be followed up until the superjacent Lower Helderberg limestone is met with, resting conformably upon the sandy layers capping the section of the Hudson series.

At the Indian Ladder, a few miles west of Albany, about 300 feet of the Hudson series is shown in the section. The rocks here consist of alternating shales and sandstones. Near the summit a massive belt of sandstone, thirty feet or more in thickness, occurs just beneath the *Tentaculite* limestone of the Lower Helderberg. This sandstone and the sandstone beds interbedded in the shales are the *grits* of the older writers. The only fossils I found at this locality were *Orthis testudinaria* and *Trinucleus concentricus*.

At Knowersville, about seventeen miles from Albany, the Lower Helderberg limestone is conformably superjacent to the Hudson shale. The section, so far as it goes, is essentially the same as at the Indian Ladder. In explorations for gas in Albany county, a deep well was drilled at Knowersville,

* Reports upon the Geographical and Geological Explorations and Surveys West of the 100th Meridian, under Wheeler, vol. IV, 1875, pp. 19, 20.

starting 595 feet vertically below the base of the Lower Helderberg limestone. It is reported that the strata passed through were gray shales and alternations of gray and black slates, which in places were quite calcareous and contained occasional thin beds of sandstone. At the depth of 2,880 feet, the Trenton limestone was struck; adding to this the 595 feet of shales and sandstones between the mouth of the well and the base of the Lower Helderberg limestone, we have a total thickness of 3,475 feet for the strata between the Lower Helderberg and the Trenton limestone on the west side of the valley of the Hudson.* This section is of great interest, as it proves beyond question that there is a great series of shales and interbedded sandstones between the Lower Helderberg and the Trenton limestone in the valley of the Hudson. If we go down the valley of Norman's kill until the upturned rocks are met with, we shall have little doubt that the latter are equivalent to a portion of the section passed through by the well. That the graptolite-bearing beds of the Hudson valley are low in the section is proved by the fact that no graptolites, with the exception of one or two wide ranging species, are known in the upper portion, immediately along the base of the Helderberg mountain.

If the geologist follows along the contact of the Hudson series with the Lower Helderberg to the Schoharie kill, and then proceeds down the stream to the valley of the Mohawk, he will pass over a large portion of the section penetrated by the well, and, in the valley of the Mohawk, find that the series rests conformably upon the Trenton limestone, and that the base is formed of dark Utica shales.

I next studied the strata on the eastern side of the Hudson, in Washington and Rensselaer counties, and found a development of rocks characterized by the graptolites of the Hudson terrane. They may be separated into three divisions on the bases of lithologic character and geographic distribution: 1. The dark argillaceous shales of the area between the western border of the county along the Hudson river and the great fault that skirts the western base of the range of hills separating the hilly country from the low, flat land of the river valley. 2. The silicious cherty beds, the green and red slates, and the dark argillaceous shales that occur, associated with them, over the central and interior portions of Washington county. 3. The dark argillaceous shales and green hydromica schists of the still more eastern Taconic range. There is not space for a full description of the rocks. They are largely formed of shales and sandstones and silicious slates, dipping to the eastward at an average angle of 40°. One section measured in Greenwich, Washington county, gives a thickness of 2,500 feet; the graptolites occur 400 feet and 1,700 feet above the base, and over the upper

* The data relating to the Knowersville and Knox wells are taken from a paper by Mr. Charles A. Ashburner "On the Petroleum and Natural Gas in New York State," 1888, pp. [illegible]

graptolite beds lie the red roofing slates. At one locality 8 genera and 13 species of graptolites were found, all of which are identical with those found at the Norman's kill locality.* The strata of the Hudson terrane cannot be delimited clearly, as the base and summit of the series are not shown on the east side of the river. I have estimated the upper division, composed of cherts and shales, and green and red roofing slates, at 3,000 feet; and the lower division, composed of calcareous sandstone and shale and dark argillaceous shales, at 2,000 feet, which gives a total thickness of 5,000 feet for the Hudson terrane on the east side of the river.

In tracing the Hudson terrane westward in the valley of the Mohawk, it is found that the Utica shale and the lower slaty portion of the Lorraine section occupy the entire section between the Trenton limestone and the Oneida conglomerate. At Utica, the Utica shale is 710 feet in thickness; and the entire upper portion of the Hudson terrane, consisting of shales and sandstones in Albany and Schoharie counties and of the same character of rock in the Lorraine section, is represented by 90 feet of somewhat silicious, and, in places, sandy shale. At the section a little southeast of Utica, the fauna is essentially that of the upper limit of the Utica zone in the Lorraine section, and practically the same as the fauna discovered by Mr. Beecher near Albany. The upper or true Lorraine fauna has not, to my knowledge, been found to the eastward of this locality. At the city of Rome, fifteen or sixteen miles west of Utica, the sandy beds become more frequent as interbedded layers in the shale, and the fauna is larger and more like that of the upper portion of the Lorraine section.†

The explanation of the absence of this upper fauna in the beds beneath the Lower Helderberg limestone, in the Hudson river valley section, appears to be found in the area of non-deposition of the upper beds in the vicinity of Utica. That the fauna is not present in the valley of the Hud-

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**Coenograptus gracilis*, Hall.
Didymograptus serratulus, Hall.
" *sagittarius*, Hall.
Leptograptus subtenuis, Hall.
Dicellograptus divaricatus, Hall.
" *sextans*, Hall.
Dicranograptus ramosus, Hall.
" *furcatus*, Hall.
Climacograptus bicornis, Hall.
" sp. undt. (occurs at Norman's Kill).
Diplograptus pristis, Hall.
" *spinulosus*, Hall.
" *whitfieldi*, Hall.
Germs, 2, occurring also at Norman's Kill.

†The following species constitute the fauna found at Rome, New York:

Dendrograptus simplex, Walcott.
Palæaster, sp.?
Heterocrinus heterodactylus, Hall.
Lingula æqualis, Hall.
Crania, n. sp.
Pholidops subtruncata, Hall.
Strophodonta, sp.
Leptæna sericea, Sowerby.
Orthis testudinaria, Dalman.
Ambonychia radiata, Hall.
Modiolopsis modiolaris, Hall.
" *anodontoides*, Hall.
" *curta*, Hall.
" *faba*, Hall.
" *cancellata*, Walcott.
Avicula insueta, Conrad.
Cleidophorus planulatus, Conrad.
Orthodesma parallelum, Hall.
Tellinomya levata, Hall.
Murchisonia milleri, Hall.
Carinaropsis patelliformis, Hall.
Bellerophon bilobatus, Sowerby.
" (*cancellata*) *textilis*, Hall.
Cyrtolites ornatus, Conrad.
Serpulites dissolutus, Billings.
Plumulites jamesi, Hall and Whitfield.
Acidaspis trentonensis, Hall.
Triarthrus beckii, Green.
Asaphus platycephalus, Stokes.
Calymene callicephala, Green.
Trinucleus concentricus, Eaton.

son is fairly well established; that it is present in the Mississippi valley or the interior of the continent is well known. The barrier that prevented the fauna of the interior sea from extending into the valley of the Hudson during the later part of the Hudson period appears to have been a shallowing of the sea through central New York about the time of the deposition of the passage beds between the Utica shale and the Lorraine shales, as shown in the Lorraine section. To the west and north of Rome, the Hudson terrane increases in thickness; and at Lorraine, in Jefferson county, I measured the following section the past summer:

Section along the south branch of Sandy creek, Jefferson county, N. Y.

	Feet.
1. Trenton limestone as exposed in the town of Ellisburgh	25
2. Dark bituminous shale in bands, alternating with a smoother lead-colored shale. Thin layers of a gray, fine-grained, calcareous sandstone occur at various horizons in the shale. This shale is characterized by the fauna of the Utica shale*	180

FOSSILS: *Endoceras proteiforme, Triarthrus beckii, and Trinucleus concentricus.* At 150 feet up in the shales a few minutes' work of collecting gave: *Leptæna sericea, Orthis testudinaria, Cleidophorus planulatus, Tellinomya*, sp. und., *Triarthrus beckii*, and *Trinucleus concentricus.**

3. Alternating bands of shale and gray, fine-grained, calcareous sandstone; the shale predominating	100

FOSSILS: *Diplograptus pristis, Hippothoa inflata, Paleschara* (sp. undet.), *Monticulipora* (2 sp. undet.), *Pholidops cincinnatiensis, Trematis terminalis, Leptæna sericea, Strophomena alternata, Orthis testudinaria, Zygospira modesta, Avicula insueta, Modiolopsis anodontoides, Cleiodophorus planulatus, Nucula levata, Bellerophon cancellatus, Pleurotomaria* (small sp. undet.), *Endoceras proteiforme, Triarthrus beckii, Calymene callicephala.* At the summit of this belt I found: *Pholidops subtruncata, Leptæna serica, Orthis testudinaria, Cleidophorus planulatus, Ambonychia radiata*, and *Triarthrus beckii.* †

4. Gray, fine-grained, calcareous sandstone, with partings of black and drab shale,‡ yielding on Sandy creek the following fauna: *Leptæna sericea, Strophomena alternata, Ambonychia radiata, Modiolopsis modiolaris, Cleidophorus planulatus*, and *Calymene callicephala.* On the Salmon river, at Pulaski, Oswego county, the base of the series is seen and about fifty feet of strata. Fossils are abundant, but as they are better preserved in the drift to the south in Lewis and Oneida counties, the following typical species only were collected: *Monticulipora discoidea, M. gracilis, Cruziana*, sp., *Glyptocrinus decadactylus, Leptæna sericea, Strophomena alternata, Ambonychia radiata, Modiolopsis modiolaris, Nucula levata, Cleidophorus planulatus, Cyrtolites ornatus, Cornulites curvatus*, and *Calymene callicephala.* At Salmon river falls the summit of this series is seen just above

* On the line of the section, the first forty feet of the shale is concealed by drift deposits, but on the north branch of Sandy creek may be seen in numerous exposures.
† This is the highest zone at which *Triarthrus beckii* was found.
‡ On the line of Sandy creek section there is about 75 feet of this series of rock exposed.

	Feet.
the falls, and 130 feet of strata are shown at the falls and below. The strike of the beds at Pulaski and at the falls is nearly the same, and the difference of altitude between them is 320 feet. Adding the thickness of the exposure at Pulaski to the supposed concealed thickness (320 feet) and the thickness at the falls (130 feet), we have	500

FOSSILS: This belt is characterized by the upper Lorraine fauna, as represented by the following species: *Orthis testudinaria*, *Modiolopsis modiolaris*, *Murchisonia milleri*, *Cyrtolites ornatus*, etc. From the drift blocks of the division there have been collected: *Monticulipora discoidea*, *M. lens*, *M. mamillata*, *M.* (2 sp. undet.), *Glyptocrinus decadactylus*, *Leptæna sericea*, *Lingula quadrata*, *Orthis erratica*, *O. biforata*, *O. occidentalis*, *O. testudinaria*, *Pholidops subtruncata*, *Strophomena alternata*, *S. alternata* var. *nasuta*, *S. tenuistriata*, *Ptilodictya* (sp. undet.), *Bellerophon bilobatus*, *Cyrtolites ornatus*, *Murchisonia bellacincta*, *M. gracilis*, *M. milleri*, *Pleurotomaria subconica*, *P. trophidophora*, *Raphistoma lenticulare*, *Endoceras* (sp. undet.), *Orthoceras* (4 sp. undet.), *Ambonychia radiata*, *Avicula demissa*, *Cleidophorus planulatus*, *Lyrodesma poststriatum*, *L. pulchellum*, *Modiolopsis curta*, *M. faba*, *M. nasuta*, *M. modiolaris*, *M. pholadiformis*, *M. truncata*, *Orthodesma contractum*, *O. parallelum*, *Conchicolites flexuosus*, *Acidaspis* (sp. undet.), *Asaphus platycephalus*, *Calymene callicephala*, and *Trinucleus concentricus*.

5. Gray sandstone	30
	810

The basal beds of gray sandstone are not seen in continuous outcrop between Salmon river falls and the Medina sandstone. At Fultonville, Oswego county, a well passed through the Medina, and thence through the gray sandstone and Lorraine shales to the Trenton limestone. The record of the well gave:

Medina sandstone	400	feet.
Lorraine sandstone and shales	880	"
Dark shales (Utica)	120	"
Trenton limestone	650	"
	2,050	"

This result indicates a thickness of 1,000 feet for the rocks of the Hudson period in northwestern New York, and the measured and estimated sections give 810+ feet, to which there is to be added the thickness of the sandstone beds beneath the red Medina sandstone.

Comparing these sections with that of the Hudson valley, they are found to be less than one-third of its thickness; but they are characterized in the same manner, in the upper portion, by interbedded sandstones and calcareous sandstones alternating with shales, and in the lower portion by a considerable development of dark argillaceous shales. Comparing the fauna, we find

that the forms of the upper part alone of the Utica zone occur within the valley of the Hudson, and that the great graptolitic fauna of the Hudson valley is largely unknown in the interior of the state. It is probable that the graptolitic fauna was prevented from spreading over the interior of the state by some such barrier as subsequently excluded the interior continental fauna of this period from the valley of the Hudson.

As described by Professor Orton, in the sixth volume of the Geological Survey of Ohio, published in 1888, the Hudson River group in southwestern Ohio consists of alternating beds of limestone and shale, the latter of which is commonly known as blue shale. The entire thickness of the series in southwestern Ohio is about 750 feet. He divides the series into lower and upper. The lower is known as the Cincinnati division, and the upper as the Lebanon division. The Cincinnati division has a thickness of from 425 to

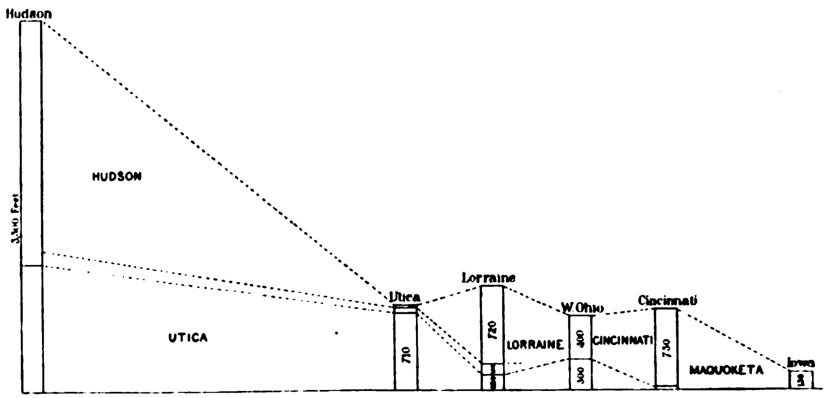

FIGURE 1.—*Diagram illustrating the relative thickness of the formations referred to the Hudson terrane in New York, Ohio, and Iowa.*

The sections are arranged on this diagram on the same relative scale. A description of each will be found in the text. A number of sections are known between western Ohio and Iowa, in Illinois, that show a gradual thinning of the Hudson toward the northwest.

450 feet, and the Lebanon division he fixes at about 300 feet. The divisions are separated on both paleontologic and stratigraphic grounds. In drilling for gas in the vicinity of Findlay, the Utica shale was met with at a depth of 800 feet. It is a black shale containing one of the most characteristic fossils of the Utica shale, viz., *Leptobolus insignis*. This bed of shale has the normal thickness of the Utica shale in New York; *i. e.*, 300 feet. The Utica shale thus discovered and defined is a constant element in the deep wells of northwestern Ohio. Its upper boundary is not always distinct, as the Hudson River shale that overlies it sometimes graduates into it in color and appearance. No great falling off of black shale appears in the Dayton well, but at Middletown the driller reported a sharp boundary between the gray shale, 320 feet thick, and black shale 100 feet thick; the latter

directly overlies the Trenton limestone. At Hamilton the same driller reported the boundary at forty feet, and the black shale was here reduced to thirty-seven feet, according to his record. From these and similar facts it appears that the Utica shale is much reduced and altered as it approaches the Ohio valley, and is finally lost by the overlap of the Hudson River shale in this portion of the state and to the southward.

A comparison of the fauna as obtained at Lorraine with that of the Cincinnati section shows nearly all of the Lorraine species at Cincinnati; also, that they have relatively the same range in the section. This comparison has been made in a tentative way, but so far as it has gone it shows a surprising equality in range of species in the two sections. Comparing the section at Lorraine, as I have already stated, the fauna of the passage-beds from the Utica shale zone is almost identical with that of the zone discovered near Albany, which, from the general character of the strata in the valley of the Hudson, I presume to be at about the same stratigraphic horizon in the section.

Value of the Term.

The use of the name Hudson River group has been attended with more or less uncertainty ever since it was promulgated by the geologists of the New York Survey. Of the board composing that Survey, Dr. Mather, Mr. Vanuxem, and Professor Hall favored the use of the term, while Dr. Emmons used Lorraine and Mr. Conrad, Salmon river, for the same series of rocks. This uncertainty was further increased in 1862 by the statement of Professor Hall that the term Hudson River group could not be extended to include the rocks of central and western New York and the Ohio valley between the Trenton limestone and the Upper Silurian rocks. Under the influence of Professor Hall's withdrawal of the term, Messrs. Meek and Worthen proposed, in 1865, the use of the name Cincinnati, saying:

"As it is now acknowledged that the rocks along the Hudson river valley, to which the name 'Hudson River group' has been applied, belong, as long maintained by Prof. Emmons, to a different horizon from the so-called Hudson River rocks of western New York and the states further westward, it seems to be an awkward misnomer to continue to apply the name 'Hudson River group' to these western deposits. Its subdivisions, it is true, have received various lithological names, such as Utica Slate, Frankfort Slate, Lorraine Shale, etc.; but as each of these names will probably be always directly associated in the minds of geologists with the particular subdivision to which it was originally applied, while neither of them is applicable to the lithological characters of the whole series, we cannot, without creating confusion, so extend its signification." *

The term Cincinnati group was adopted by the geologic surveys of Illi-

* Proc. Acad. Nat. Sci. Phil., vol. 17, 1865, p. 155.

nois and Ohio, and came into general use in the west. Some geologists, however, preferred to use the term Lorraine, as proposed by Dr. Emmons, on the ground of priority; and when, in 1877, Professor Hall stated that he had been led into error in considering the rocks in the valley of the Hudson as of primordial age, or older than those of the Lorraine and Cincinnati sections, and that he thought the term Hudson River group should be used in geologic nomenclature, as it had specific value, the tendency to return to the use of the name became more and more apparent among geologists. At the same time, however, some geologists continued to use the name Lorraine; others retained Cincinnati, and in Iowa, Maquoketa was used.

Wishing to know more of the typical rocks included under the name Hudson River group by Dr. Mather in his survey of the Hudson River valley, I examined the sections both on the west and on the east sides of the river, with the result which I have already recounted. I then examined and studied carefully the sections at Lorraine, on the Salmon river, and in the Mohawk valley; and on returning from the field I read the descriptions of the supposed equivalent series of rocks as found in Ohio and portions of the Mississippi valley.

The result of this study is the retention of the term Hudson* for the series of strata between the Trenton limestone and the superjacent Upper Silurian rocks. The sections in the valley of the Hudson embrace all the strata between the Trenton limestone and the Upper Silurian, and include the Utica shale formation, the intermediate silicious slate, as represented by the lower portion of the Lorraine shales, and also the alternating sandstone and shales of the Lorraine section. It is true that the typical fauna of the upper portion of the series is not present in the valley of the Hudson so far as known; but we must recollect that stratigraphic geology preceded paleontology and the identification of horizons by paleontologic evidence, and that when by practically continuous stratigraphy a formation has been traced from one area to another the name applied to the formation where first discovered and named will hold good even though the rocks at the typical locality do not contain the fauna which characterizes the horizon at some other locality. The absence of a fauna in such a case does not injure the correlation; its presence would of course strengthen the correlation, but in the case in hand it does not appear to be essential.

In thus adopting the term Hudson for the entire series, I do not wish it understood that I favor dropping the local names Lorraine, Cincinnati, Maquoketa, etc. The term Hudson is used in the generic sense, to include a group of formations that occur between the Trenton limestone horizon

* The second part of the original name is dropped in order to bring it into harmony with the names Trenton, Chazy, Niagara, etc., and adapt it to its position as a generic term.

and the Upper Silurian or Niagara horizon. This idea is expressed in the following tabulation:

Terrane.	Formations.
Hudson - - -	Hudson River shales and grits. Utica shale. Frankfort shale. Lorraine shale and sandstone. Salmon River sandstone and shale. Cincinnati shale and limestone. Nashville shale. Maquoketa shale.

In tabulating the formations in this manner the local names are preserved and, at the same time, the position in the geological series is indicated by the term Hudson. Thus, in speaking of the Hudson rocks in western New York, we say the Hudson terrane consists in Lorraine of the Utica shale, the Lorraine shale, and the Lorraine sandstone; and, on the Salmon river of the Salmon River shale and sandstone, and the Pulaski shale.

In reply, then, to the question, "What is the value of the term Hudson River in the light of recent geologic research," I think we may say that its essential part is established by the rules of geologic nomenclature, except against the prior use of the name Salmon River. In relation to this, I think all geologists will agree that the interests of geology will be subserved by leaving the term Salmon River in the obscurity in which it has so long remained. The term Hudson has a clear and distinct meaning. It is known in the geologic nomenclature of America and Europe, and it is sustained by the testimony of the rocks in the valley of the Hudson.

DISCUSSION.

Professor JAMES HALL: I should like to express my great gratification with the results of Mr. Walcott's investigations. It leaves nothing, I believe, now to be desired beyond the bringing out of detailed results, which I dare say he will do in the future.

Professor W. M. DAVIS: This discussion gives me a desired opportunity to explain a small matter, since I fear that a position I took several years ago bearing on this question has been somewhat misunderstood. Some time ago, when visiting the Hudson river valley with a class of students in our Summer School of Geology, we examined the relations of the Hudson River rocks and the overlying Helderbergs. The question of the relative conformity of these two divisions had been much discussed, and we sought to see how far the evidence there bore upon it. There are several sections, one particularly on the Catskill stream not far from the town of Catskill, that give fair opportunity for close examination of the lower and upper rocks. My conclusion at that time was that, as far as that district was concerned, it would be unsafe to say that there was a distinct unconformity between these Hudson river rocks and the overlying Helderbergs. I did not wish to assert that there was absolute conformity, but it seemed to me that with the facts at Catskill alone it would be difficult to demonstrate unconformity; that if there were at all other localities a perfect conformity, the observations at Catskill need not disagree with that relation; that the difference of altitude of the lower and upper rocks about the Catskill was a discordance such as might be produced by the folding together of the dissimilar rocks in that region—the amount of discordance not being more than is often observed as the result of folding masses of unequal resistance. But, on the other hand, at Rondout, farther down the Hudson valley, it is manifest that there is a strong unconformity, and I should not wish for a moment to use the observations at Catskill as proving a conformity at Rondout or anywhere else. The point is that, as far as Catskill is concerned, the facts do not compel the belief in the unconformity of the Helderbergs to the Hudson formation, and that if no other locality of contact of these formations were known, their relation might still be in doubt.

Mr. WALCOTT: I have read Professor Davis's papers with interest and profit, and I understood him to mean that the conformity between the two series was only in the Catskill region, and that there was an unconformity at Becraft's Mountain. From the latest paper published by him I obtained the impression that he supposed a conformity to exist also at one of the sections in Rondout. I may have misinterpreted his description.

Professor DAVIS: At Rondout there is a very striking outcrop of the Hudson formation dipping at a steep angle to the east, with the Coralline limestone upon it dipping at a tolerably steep angle to the west, and fitting into deep inequalities of the beveled surface of the under formation. The contact could not have been made by a fault; it was a distinct unconformity. Intermediate between Rondout and Catskill I have found a valley where the structure of the two rocks is clearly discordant—so much so that one could hardly ascribe the discordance to the uneven folding of rocks of different resistance. On going up the Hudson valley beyond Catskill to the Schoharie region, the Hudson and Helderberg rocks seem to be conformable, both being essentially horizontal; but the outcrops near their contact are not very extended; an unconformity by erosion might escape detection there.

Mr. WALCOTT: In this connection I wish to place on record a recent disdiscovery of Niagara fossils* in the tilted and upturned strata east of the Hudson, in the township of Cambridge, Washington county, New York. The section at this point consists of a mass of dark shales with interbedded chert, and small lenticular masses of limestone in which the fossils occur. The stratigraphic relations of this mass of rock to the strata of the Hudson terrane to the west were not ascertained. This discovery is of interest, as it proves that in this area of disturbance, unconformity, and usually of apparent nondeposition of the rocks of the Niagara age, there was one tract in which the Niagara fauna existed, became imbedded, and was not removed by subsequent erosion.

* *Orthis flabellum*, Sowerby; *Orthis*, 2 sp. undet.; *Leptæna transversalis*, Hall; *Strophomena rhomboidalis*, Wahlen; *Rhynchonella neglecta*, Hall; *Merista dubia*, Hall; *Ceraurus*, of the type of *C. insignis* (Beyrich) Hall, and *Illænus* (fragment of head).

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SOME RESULTS OF ARCHEAN STUDIES.

BY ALEXANDER WINCHELL, A. M., LL. D., F. G. S. A., PROFESSOR OF GEOLOGY AND PALÆONTOLOGY IN THE UNIVERSITY OF MICHIGAN.

(*Read before the Society December* 28, 1889.)

ANALYSIS.

CONFLICTS OF OPINION IN THIS FIELD.

The present memoir is simply a synopsis of facts observed by the author, with a few obvious inferences, touching the structure and classification of the older rocks of the Northwest. Citations will be made from other investigators where the facts or opinions appear to throw important light on the problems which the author has studied.

The motive for offering this presentation of the results of personal studies exists in the vague and conflicting state of opinion respecting the older rocks. This concerns not only their genesis and geological history, but their constitution and characters and even their sequence and mode of mechanical relation to each other. On the one hand, there are geologists of reputation who maintain that most granitic and gneissic rocks have originated directly

from a state of molten fluidity; and this view is extended even to the so-called crystalline schists and to many other less crystalline rocks. On the other hand, geologists of equal reputation regard the crystalline schists and gneisses as ancient marine sediments, altered profoundly by the agents which have acted upon them during the vicissitudes of terrestrial history; and this view is extended also to the granitic or massive conditions of the fundamental rocks. The representatives of the latter school, however, admit that extreme metamorphic action has sometimes reduced the ancient sediments to a state of igneo-aqueous plasticity, and that in such condition the materials have been squeezed into fissures and spaces of diversified forms. They recognize the fact that large volumes of marine sediments have probably consisted of volcanic ashes, lapilli, pebbles, and larger fragments which have been spread over the ocean's floor by the same agencies and in the same manner as detrital materials derived from eroded land-surfaces; and they, equally with the opposing school, discern the evidences that lava-like eruptions have occurred in every age of geologic history.

What is less to be expected than differences of opinion on speculative questions like these is the great diversity of views respecting matters open to observation. On the one hand, geologists of wide reputation and learning contend that the entire series of pre-fossiliferous rocks constitutes but one group or system. On the other hand, geologists equally competent recognize an obvious division into two groups or systems, while some go to the extent of characterizing not less than five systems beneath the oldest zone of life. Those who recognize two or more pre-fossiliferous systems are not agreed in reference to their order of superposition. One maintains that the Montalban is below the Huronian, another that it is above. One affirms the Hastings series to lie in the horizon of the Upper Laurentian, another places it in the horizon of the Huronian. One recognizes Lower Laurentian in conformable contact with the crystalline schists, another regards the rocks as Upper Laurentian. Systems in juxtaposition have to-day been pronounced conformable, to-morrow unconformable, and the next day again conformable. Systems have been named as holding definite chronological sequence which by others are affirmed to be but lithological states, having no chronological significance.

With such a diversity of views entertained, not only within the deductive but also in the inductive province of the science, one can almost justify the severe verdict of Whitney and Wadsworth, rendered after a searching examination of the records of opinion found in American geological literature and thus stated in their "Résumé:"

"We think that it is impossible for any unprejudiced worker in this department of science to peruse with care the preceding pages and not feel obliged to admit that the geology of a large portion of this country, and especially that of Canada and New England, is in an almost hopeless state of confusion. We think that it must have

been made clear to the candid mind that the geologist would find himself completely baffled who should endeavor to obtain any definite knowledge of the real nature and order of succession of the rocks which cover so large a portion of the region in question from the study of that which has been published with regard to them. We believe that we are justified in going still farther and saying that our chances of our having at some future time a clear understanding of the geological structure of Northeastern North America would be decidedly improved if all that has been written about it were at once struck out of existence." *

We may do our predecessors the simple justice to admit that they have been engaged on difficult problems and have treated them with ability equal to that employed by our contemporaries, and yet feel, with Whitney and Wadsworth, that very much remains to be desired.

After the foregoing representation of the state of our knowledge of the older rocks, it may appear presumptuous on the part of the present writer to make an attempt where so many have fallen short of the success at which they aimed. There are two circumstances, however, which lead the writer to hope that he may be able to contribute something to a final understanding of the structural relations of our pre-fossiliferous rocks: 1. He has had the good fortune to study them over an area in which they lie apparently in their original relative positions for hundreds of miles in uninterrupted extent, while the older investigations have been conducted in the midst of wearisome and perplexing convolutions, plications, and overturns. 2. He has made his field observations for himself and has not depended on the reports of subordinates; and, besides earlier studies, he has spent recently the entire working period of two seasons camping on the formations under investigation. It may be added that he has extended his researches into the fields reported on by others and has collated the conclusions reached by them with the facts observed by himself. He thinks, therefore, it will not be regarded presumptuous to offer his contribution to the common stock of knowledge.

The Northwest compared with New England and Canada.

In most parts of the northern United States and eastern Canada, where the oldest rocks present themselves at the surface, their condition, as represented, is that of more or less crumpled masses. In the Adirondacks the granites, norites, and gneisses are thus characterized by Emmons,† though, according to the methods of his time, the mineral constituents of the crystalline rocks were regarded more important than the structural features. In Vermont the gneisses are reported by E. and C. H. Hitchcock as "exceedingly contorted,"‡ insomuch that great difficulty exists in determining aver-

* "*The Azoic System and its proposed Subdivisions*," by J. D. Whitney and M. E. Wadsworth, Bulletin Museum of Comparative Zoölogy, Geological Series, Vol. I [pp. i–xvi and 331–565], pp. 519–520.
† *Geology of New York*, Part II, 1842, 2d District, especially pp. 23 and 77.
‡ *Geology of Vermont*, Vol. I, 1861, p. 518.

age strikes. The late survey of New Hampshire is apparently compelled to limit itself largely to a study of the surface distribution of the crystalline rocks. It seems to be impossible to grasp the general structure in one conception. In the pages of description little use is made of phenomena of dip and strike. It is true that pages are devoted to tables of dip and strike, but they stand as isolated and meaningless facts. The neglect to unify them in a structural conception is apparently due to the extreme difficulty of the task. There is little persistence of dip or continuity of strike. The figures in contiguous regions are as diverse as can be conceived*. In the midst of this bewildering chaos Professor Hitchcock has recognized certain generalizations which lie on the road to a correct interpretation, but it was impossible, in the light of facts then in possession of geologists, to follow their leading to a full solution of the Archæan problem. To these I shall refer on some subsequent occasion.

The intricacies of rock-arrangement through western Massachusetts are represented in the conflict over the Taconic question, the sounds of which have not yet ceased to reverberate. These obscurities were traced by the brothers Rogers into Pennsylvania and Virginia. In eastern Massachusetts the lithologic arrangements are so ambiguous that the able geologists who live upon them are undoing each other's schemes of interpretation with a zeal and emphasis which would seem to imply that opposites must both and all be true. In the Canadian field the remarkable structural investigations of Sir William Logan and his co-laborers have long since shown a state of disturbance which sets all method at defiance. The truth of this is illustrated in almost every annual report published from 1842 to 1866.

Quite in contrast with these structural complications is the lithologic system of northeastern Minnesota. From Vermilion lake to South Fowl lake the semi-crystalline schists pursue a strike varying little from east-northeast for a distance of twenty ranges of townships, or about 130 miles along the strike. Beyond this they extend, largely concealed by overlying pre-Silurian rocks, in the same general direction to Thunder bay, 45 miles further. Throughout this distance the schists present but a single fold, and their structural relations to each other and to the crystalline schists and gneisses of higher antiquity become a matter of comparatively easy observation. In the regions west and northwest of Vermilion lake, at least as far as the Lake of the Woods, similar simplicity of structure prevails, though, so far as I know, there is no other area of equal extent in which a single system of dips and strikes persists throughout.

*C. H. Hitchcock and J. H. Huntington: *Geology of New Hampshire*, Vol. II, 1877, chaps. v to x, especially pp. 423–'4, 488–'9, 504–'6; pl. xxi, p. 525; pp. 595–'7, 600, 616–'9, 621–'2. The complexity of the structure is recognized in the twelve sections across the State shown in the Atlas and described in Vol. II, pp. 636–657. It is revealed in the numerous and radical changes of view set forth in the successive publications of the Survey.

Areas of Granitoid and Gneissoid Rocks.

The rocks which on the evidence of relative position would be regarded as the oldest rocks accessible to observation in the Northwest are granitoid, as every one understands; but I have not found, as yet, any general granitoid nucleus of the continent, occupying the surface uninterruptedly, in any direction, for more than a hundred miles. Even the granitoid areas are not occupied chiefly by rocks conforming to the standard definition of granite—a non-bedded and non-foliated mixture of quartz, feldspar, and mica, or of quartz, feldspar, and hornblende. Limited areas approaching, or perhaps attaining, this condition are found; but the principal expanses of crystalline rock are gneissic—consisting of quartz, feldspar, and a dark element, with the quartz in many cases deficient in amount, but also very extensively disseminated in porphyritic development. The feldspathic element is predominantly orthoclase, but generally one or more triclinic feldspars is also present. The dark or ferro-magnesian element is generally biotite or hornblende, or both together. Sometimes muscovite appears with one or both of these, and occasionally it excludes them. In rare cases the dark element is augite,* and not unfrequently individuals of hornblende are found with augitic nuclei. Over considerable areas the hornblende has undergone uralitization, and even chloritization. A large part of the hornblende, however, is black, lustrous, and fresh. The orthoclase is often found in porphyritic development, but generally it occurs in the ordinary granular state. In the chloritic portions the feldspar is chiefly of late generation, and forms a more or less perfect groundmass, with a greenish stain in the vicinity of the amorphous, chloritized hornblende. In mineralogical composition the areas strictly granitoid are undistinguishable from those properly gneissoid. In structure the distinctions of successive generations are less obvious, and the chloritization of the hornblende has made less progress.

Within the limits of northeastern Minnesota four distinct areas of granitoid and gneissoid rocks have been surveyed. The accompanying diagram shows their relative positions.

These are the Basswood Area, the White Iron Area, the Saganaga Area, and the Vermilion Area, so named from large lakes lying upon their borders. Only the White Iron and Vermilion Areas have been followed along all their borders. They are the only ones embraced wholly in Minnesota.

The *White Iron Area* is elongated from Snowbank and Disappointment lakes southwestward to Birch lake and beyond. It is overlain along its southeastern border by the great gabbro formation; and this, at one place, laps quite across the Area, dividing its surface exposure into two areas.

*M. Alf. Lacroix has very recently made a study of pyroxenic gneiss from various parts of Europe. "*Contributions à l'étude des gneiss à pyroxène et des roches à wernérite*," Paris, 1889, pp. 1–280.

This mass consists of hornblende gneisses, generally vertical, and striking northeast. The orthoclase is reddish, and the individuals are mostly large—up to three-fourths of an inch in diameter. Very rarely muscovite is present, and not more frequently biotite. The nature of the rock in places becomes decidedly quartzose. A few pebbles of granulite and quartzite are disseminated through it. This body of gneiss, or granitic gneiss, is everywhere around the shores of White Iron lake diversified by numerous inclusions of

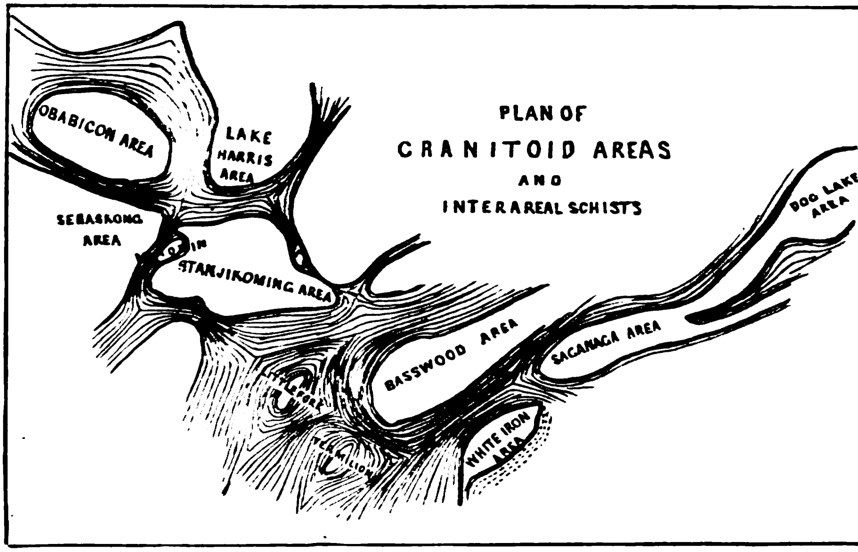

FIGURE 1.—*Diagram of Granitoid and Gneissoid Areas in Northeastern Minnesota* and parts of Canada.*

mica and hornblende schist. This striking phenomenon I shall refer to in another connection.†

The *Saganaga Area* of granitoid rocks holds Saganaga lake, with its long southern arms centrally located, and lies in Minnesota on the fourth and fifth ranges of townships, stretching north five or six miles across the international boundary, where it is limited by semi-crystalline schists. Toward the east-northeast it extends into Canada an unknown distance, along a zone north of Gunflint and North lakes. This mass, as a whole, is distinctly a quartz-bearing syenitic gneiss. It is nowhere characteristically massive. The quartz occurs throughout in large angular individuals, attaining diame-

* In default of a map to accompany the present memoir it may be useful to mention that the locations of most of the small lakes in northeastern Minnesota are conveniently shown on the map forming Plate XLI (facing p. 418) of the *Seventh Annual Report U. S. Geol. Survey*. Names should be changed, however, as follows: "Mountain L." (southeast of Basswood) to Ensign lake; "Carp L." to Sucker lake; "Ogiskemanissi L." to Ogishke-muncie lake—the names employed in the Minnesota reports being taken from the plats of the U. S. Land Survey. A more complete map may be found in the Fifteenth Ann. Rep. of the Minnesota Survey.

† The White Iron Area is described in my report of 1886, "*Fifteenth Annual Report Minnesota Geological and Natural History Survey*," pp. 74–81.

ters of half an inch to three-quarters. In composition the rock varies considerably. The prevailing dark element is hornblende, but this is locally replaced by muscovite in moderate sized folia, but in places, near the borders of the area, in very small scales. In one place, a mile within the southern boundary, extensive generations of quartz occur, imbedded in a feldspathic groundmass. The quartz, in places, is sericitic, and actually passes into cuneately brecciated patches of sericitic material, only less schistic than the sericitic beds of the Kewatin, to be described subsequently. In this region the dark element is wanting. In other places this gneissoid mass assumes the constitution and structure of a mica schist. In certain regions the hornblende has degenerated to a chloritic state. This condition, when present, is always found near the borders, and consequently, as we shall see, in the higher portion of the crystalline mass. At one point, in the southern part of the body of Saganaga lake, the formation seems to consist of a chlorito-augitic groundmass, with a small quantity of light feldspar and a greenish mineral disseminated.

This Area includes also Granite, West-Seagull, and Seagull lakes, and the general character of the formation is everywhere preserved. The so-called Giant's Range stretches a little north of east, and, passing Granite lake, enters Canada. The Minnesota Survey has located its southern border at sundry points, as far east as the middle of North lake. Beyond this I have no personal knowledge of it, though incomplete information from the Canadian Reports indicates its extension so as to include Dog lake, north of Thunder bay, Lake Superior.

A remarkable feature of this gneissic mass, as far as examined by myself, is the wide distribution of rounded pebbles, and their occasional aggregation into truly conglomeratic formations. The significance of this will have to be considered in another connection.

Throughout the whole extent of the Saganaga Area the rocky beds stand nearly vertical and trend east-northeast, becoming more easterly in the eastern prolongation.*

The *Basswood Area* lies upon the national boundary, through ranges nine to thirteen, or from Sucker lake to Iron lake—a sinuous line about forty miles in length. From this boundary it extends northeastwardly into Canada an unknown but rather limited distance. On the Minnesota side it has not been completely explored, but has been traced southwestward well toward Vermilion lake, while its western limit is still undetermined. It is known, however, not to extend over fifty miles from the boundary. The beds of this mass of gneissoid rock stand everywhere in a vertical position, so far as I

*The Saganaga Area has been more particularly described by me in the *Sixteenth Annual Report of the Minn. Surv.*, 1887, pp. 211–233, 292–209, 331–334.

have observed them, and they have a pretty uniform trend from northeast to southwest. The mineral composition of the mass is similar to that of the masses just noticed, but the quartz element, while generally in abundance, does not develop individuals over a quarter of an inch in diameter. The orthoclase on weathered surfaces is predominantly red, and extensive areas on Crooked lake fairly glow in the distance with a blood-red hue. The individuals sometimes attain a diameter of half an inch. In other places the feldspathic element ceases to be granular and becomes a groundmass in which sometimes grains of quartz are imbedded, but more frequently, in this condition of the feldspar, the quartz is absent or nearly so. The ferro-magnesian element is mostly black hornblende to the east of Crooked lake, but westward this is generally replaced by biotite, with occasional muscovite. Across a zone of a quarter of a mile along the boundary the dark mineral is chloritic, with little quartz, and stains the feldspathic groundmass. In this vicinity occurs a condition consisting of hornblende, menaccanite, and feldspar.*

In a southwesterly direction the shores and islands of Burntside lake afford striking examples of the nature of the formation and its relations to the overlying crystalline schists, the bedded rocks retaining uniformly an attitude nearly vertical. In this region hydromica gneiss frequently occurs, but generally the dark mineral is either mica or hornblende.†

A small oval, granitoid Area lies immediately west of Vermilion lake, including the West bay, and might be styled the *Vermilion Area*. Its longer axis is directed about N. 65° E., and its length is about twelve miles. The breadth of this Area is six miles. The rock is mostly a biotite gneiss. Its strike is not persistently northeast and southwest, but concentric with the border of the Area, and the dip is outward from the centre on all sides, gradually approaching a horizontal position at the centre. This is a very significant departure from that close adherence to a northeast strike observed in the other and larger areas.‡

From this region an expanse of mica schist extends northwest about 50 miles to Rainy lake, and this is followed by a belt of semi-crystalline schists about five or six miles wide, trending nearly N. 75° E. Beyond this we find the *Stanjikoming Area* of Lawson, inclosing all of the north-south arm of Rainy lake,§ oblong in form, with its longer axis N. 75° E., having a length of 45 miles and a width of 32. The included area is occupied by syenitic and biotitic gneisses with a border of crystalline schists and those remarkable included masses to which special reference will soon be made.

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* For geology of Basswood, Crooked, and Iron lakes see *Fifteenth Ann. Rep. Minn. Surv.*, 1866, pp. 92–119; 409–411.

† For geology of Burntside lake see *Fifteenth Ann. Rep. Minn. Geol. Surv.*, 1866, pp. 36–52; *Sixteenth Rep.*, 1887, pp. 195–'6.

‡ The Vermilion Area is described in the *Fifteenth Annual Report Minn. Surv.*, 1886, pp. 287–298.

§ For a description of the Stanjikoming Area see Lawson, *Ann. Rep. Geol. and Nat. Hist. Surv. Canada*, 1888, Part F, Report on the Geology of the Rainy Lake Region, p. 41.

On all sides of this Area occur other and similar areas, encircled by belts of crystalline schists and separated from each other, as in Minnesota, by vertical synclinally folded troughs of semi-crystalline schists. The Area on the south has just been mentioned as the Vermilion Area. Some of the others have received from Dr. Lawson special names. The *Sabaskong Area* lies northwest of this, separated from it by a belt of semi-crystalline schists about three miles wide and stretching to the Lake of the Woods. This Area is about 25 miles in diameter. Between the two areas, however, the small *Minomin Area,* which is ten miles long and five miles broad, is crowded in. Northwest of the Sabaskong Area lies the *Obabikon Area,* embracing the whole of the Grand Presqu'ile of Lake of the Woods and Whitefish bay.* It is 33 miles in greater diameter, N. 67° W., and 29 in the transverse direction. This Area, like the others, is girded by inclosing schists on all sides, except perhaps a small break at the south. The belt of schists on the northwest side attains a diameter of 20 miles. Within that breadth, however, occur half a dozen exposures of granitoid rock, each encircled by schists approaching a concentric strike. Beyond the bounding schistic belts are other gneissoid regions stretching toward the northeast, north, and northwest for distances not yet ascertained. From the Stanjikoming Area toward the east and northeast are other little exposed areas, while on the north is the so-called *Lake Harris Area.* Between the Lake of the Woods and Thunder bay, granitoid rocks are known to alternate several times with crystalline and semi-crystalline schists, but the several areas have not been circumscribed by explorations.

Within each of the areas thus indicated the underlying rock is predominantly gneissoid. It is not everywhere equally foliated. If it anywhere approaches the granitoid condition that is the part more remote from the periphery. Within some of the larger areas we find two or more granitoid centres, and around each of these the lines of gneissic foliation are concentrically arranged. Dr. Lawson states that in the Stanjikoming Area of Rainy lake the more basic gneiss occupies, within the general Area, the belt next contiguous to the environing crystalline schists; the more acid surrounds the nuclear region. The former is a syenite gneiss with little or no quartz, having a coarse texture and imperfect foliation. The more nuclear portion is essentially a biotite gneiss of medium texture, very quartzose and distinctly foliated.

Sporadic eruptions of granite occur, cutting sometimes the gneisses and sometimes the crystalline and newer schists, but of these I have no occasion to make particular mention at present.

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*For the geology of the Lake of the Woods see Lawson, *Geol. and Nat. Hist. Surv. of Canada,* 1885 Report CC.

Areas of Crystalline Schists.

Each of the granitoid Areas (see fig. 1) above mentioned is flanked on all sides by a belt of crystalline schists. These, by the Minnesota Survey, were designated, in 1886, the *Vermilion Series*. As a general formula they dip away from the periphery of the Area, and the angle of dip increases with the distance until it becomes vertical (see fig. 7). In this position they are conformable with the newer semi-crystalline schists, with which they are now in contact, and on the other side of which the crystalline schists reappear in vertical attitude, but soon leaning toward the next gneissoid mass. In the region south of the Rainy river occurs a very extensive area of crystalline schists, but wide tracts of this are horizontal or nearly so. In crossing it from north to south we discern, first, a gradual diminution of northward dip; then an approach to horizontality, followed by a change to southward dip, indicating the passage of an anticlinal. Further south the southward dip becomes vertical, and then a northward dip supervenes, indicating the passage of a synclinal. The northward dip continues to contact with the next gneissoid Area.* These undulations give opportunity to calculate the thickness of the Vermilion series, and give us a result in this place of 25,500 feet. Seldom, however, do they attain this volume. In fact, we find them presenting all degrees of attenuation, down to complete disappearance. In my computations I found them, in the interval between the Basswood and White Iron granitoid Areas, possessing a maximum thickness of 2,112 feet. Around the Saganaga Area the crystalline schists are little noticeable, while on the south side, in Minnesota, they may almost be pronounced wanting. Farther east, however, in Canada, north of Gunflint and North lakes, the south side of the Saganaga Area is found flanked by them. Observations made in the last region seem to show that the crystalline schists sometimes *disappear in the line of strike*, as if passing into gneiss.† A very remarkable occurrence is recorded by the Minnesota Survey ‡ on Disappointment lake, east of Snowbank, on the extreme northeastern border of the White Iron granitoid Area. Here is the first marked deviation from an east-northeast strike in all the distance from Tower, an interval of 55 miles. The strike in this region bends around to north-northwest. Here a hornblendic mica schist becomes conglomeratic with various kinds of crystalline rocks up to a foot in diameter. The bowlders are mostly lenticular. After a change to a nondescript rock, which has received the field designation of "muscovado,"

* For description of the geology of the Little Fork, a tributary of Rainy river, located 25 miles west of the traverse just indicated, see H. V. Winchell, *Sixteenth Ann. Rep. Minn.*, pp. 396–412. These notes indicate flat anticlinals in Town. 66, and the inference is that this is the centre of the gneissic Area mentioned by Lawson. It may be known as the *Little Fork Area*.

† *Sixteenth Minn. Rep.*, 1887, pp. 262–266. Compare with U. S. Grant's observations, *Seventeenth Minn. Rep.*, pp. 151–158.

‡ H. V. Winchell, *Seventeenth Ann. Rep.*, pp. 115–119.

the schist takes a great accession of feldspar and becomes a gneiss. This is also conglomeratic, and in some places is almost entirely composed of bowlders. The formation finally grows silicious and then diabasic, rising in ridges 150 feet above the lake. This varying conglomerate is two miles in width across the strike.

The same observer has noted similar facts on the south shore of Rainy lake:

> "In the southwest quarter of section 30, township 71-22, the mica schist is conglomeratic, containing innumerable flattened pebbles and bowlders, all changed into rock very similar to the schist. * * * A little farther east the rock assumes the appearance of a decided conglomerate, containing pebbles of granite, quartzite, and schist as large as eight inches in diameter." *

Generally, however, the Vermilion series is represented by mica schists. These are most frequently biotite schists, or biotite-muscovite schists, or biotite-hornblende schists. Transitions from one to the other are of common occurrence. Other characters of these schists are quite ordinary and do not require mention in a condensed sketch.

Structural Relations of the Granitoid, Gneissoid, and Schistoid Rocks.

The phenomena observed under this head are extremely interesting. The crystalline schists approach the gneisses under a steep inclination, very generally in Minnesota approximating to verticality. But we never observe an abrupt junction between them. They are always in strict structural conformity. In thousands of observations on the nature of their approximation I have never seen an undoubted discordance of bedding. There are no such facts in the Northwest as have been pictured in some of the text-books. But all this is not adequate proof of the absence of a chronological break. In fact, the reality of such a break is revealed in the phenomena which I am about to describe.

In passing from the interior toward the periphery of one of the granitoid areas we find portions of the neighboring schists included within the mass of the gneiss. These increase in amount as we proceed. At an indeterminate zone the volume of schist equals that of the gneiss. Then we encounter fragments of the gneiss included in the schist. The schist, meantime, becomes extremely cut by ramifying sheets of gneiss, granite, or granulite proceeding from the centre. Sometimes a very intricate net-work results. At remoter points these ramifications diminish and the schist finally presents itself in its normal and usual condition.

The portions of schist are generally angular and flattened. They are evidently fragments of schistic sheets separated from the body of the schists

* *Sixteenth Minn. Rep.*, p. 416. Such expressions as 71-72, above, refer to township and range.

and moved certain distances into the body of the gneiss. We find them of all sizes and of various thicknesses. At the points remotest from the schist body the fragments may be a foot or three feet in length, as presented edgewise at the usual outcrop. At positions nearer the schist body the fragments are larger, but generally without increased thickness. They become large flat tables turned on edge, with thickness sometimes reduced to two or three inches. Sometimes we find them broken and the pieces separated a few inches. Next, we find their dimensions extending beyond the limits of practicable observation. They appear like split-off beds of the schists. In this state their thickness diminishes, in many cases, to an inch or half an inch or even a quarter of an inch. Thus we are compelled to contemplate the mixed formation as a unit, produced by a system of alternating or interrupted activities.* These included fragments retain, generally, a surprising parallelism with the bedding of the body of schists. Even the short fragments most remote from the schists generally lie in a conformable position. The nearer sheets retain a rigid parallelism with the bedding of the body of schists, and this is always coincident with the foliation of the gneiss, when it exists. The force which separated the schistic sheets could not have been violent. The breakages which occurred could not have resulted from any eruptive action. There may have been evenly distributed pressures, and these may have floated apart the co-adapted fragments which were parted by some adequate force. But they were not generally floated out of a common plane. The evidences of violent action are wanting.

Exhibitions of phenomena such as above described are witnessed on every hand, but none surpass those found on the islands in Burntside lake. Remarkable examples are seen on White Iron lake.† The State Geologist of Minnesota remarks as follows of an occurrence on the Vermilion granitoid Area, at the western extremity of Vermilion lake:

> "Following the mica-schist bluffs westwardly, noting the fine, conformable, and increasing number of their sheets of granite, the fact suddenly flashes on the observer that the rock has become changed to a reddish-gray gneiss, and a moment's further examination only is needed to show its further conformable transition to granite, thus making a conformable passage from one extreme to the other."

Of another locality in the vicinity he says:

> "Showing the same kind of conformable interstratification downward, demonstrating the existence of a large mass of granite [gneiss] conformably interstratified in mica schist and graduating into mica schist above and below." ‡

Of the junction of the gneiss and schist at Whitefish bay of the Lake of the Woods, Dr. Lawson says:

> "The junction itself is exposed on this shore, on the face of a low cliff presenting the appearance figured in the annexed diagram, there being apparently no sharply

* See fig. 37, *Fifteenth Ann. Rep. Minn.*, 1886, p. 96.
† Ibid., pp. 37-62, 74-81.
‡ Ibid., p. 296.

defined line of contact, but a transitional series of layers of alternate gneiss and schist. These bed-like sheets of gneiss within the schist, however, *are injected*." *

Again, speaking of the same subject in a later report, Dr. Lawson, referring to these sheets, says:

"Some are acres in extent and some take the form of bands one or several miles in length by hundreds of feet in breadth, which in single sections might easily be mistaken for interstratifications with the gneiss." †

I introduce here also a remarkable record made by Dr. Lawson concerning another occurrence in the region of the Lake of the Woods:

"The interesting or prominent portion of the point is occupied by the following alternation of bands of gneiss and schist, the strike of the rocks being S. 50° E. and the dip either vertical or at very high angles to the south:

1.	Gneiss	1	foot	7	inches.
2.	Hornblende schist	54	feet.		
3.	Gneiss	11	"		
4.	Hornblende schist	60	"		
5.	Gneiss	3	"	8	"
6.	Hornblende schist	31	"		
7.	Gneiss	1	"	8	"
8.	Hornblende schist	11	"		
9.	Gneiss	20	"		
10.	Hornblende schist	22	"		
11.	Gneiss	0	"	8	"
12.	Hornblende schist	58	"		
13.	Gneiss	4	"	4	"
14.	Hornblende schist	6	"		
15.	Gneiss	0	"	6	"
16.	Hornblende schist	32	"		
17.	Gneiss	12	"	2	"
18.	Hornblende schist	13	"		
19.	Gneiss	1	"	8	"
20.	Hornblende schist	4	"		
21.	Gneiss	3	"		
22.	Hornblende schist	1	"	3	"
23.	Gneiss	1	"	6	"
24.	Hornblende schist	5	"		
25.	Gneiss	0	"	4	"
26.	Hornblende schist	0	"	8	"
27.	Gneiss	1	"		
28.	Hornblende schist	1	"		
29.	Gneiss	2	"	8	"
30.	Hornblende schist	5	"		
31.	Gneiss	100	"		
32.	Hornblende schist	12	"		
33.	Mixed gneiss and schist	20	"		
	Gneiss, indefinite thickness."‡				

* *Geolog. Report Canada*, 1885, Doc. CC, pp. 72, 73. See also Rep. 1888, F, pp. 116, 118, *et pas.*
†*Report*, 1888. p. 132.
‡ *Ann. Rep. Geol. Surv. Canada*, 1885, Doc. CC, pp. 74–75.

Dr. Lawson remarks: "These bands of gneiss alternating with the schist are for the most part regular and bed-like in their characters, but their true nature as injected sheets or dikes is sufficiently revealed."

It will be noted in the above table that the thickness of the schist beds gradually diminishes from top to bottom, while that of the gneiss beds gradually increases. This denotes advance from the gneissic side toward the schistic.

Whether these numerous and tenuous gneissic bands present the verisimilitude of "injected sheets or dikes" may be better decided after noting a state of facts which has fallen under my own observation. On the north of Gunflint lake a traverse was made northward from the Animikie slates to the Saganaga gneissoid area. As usual a belt of crystalline schists was

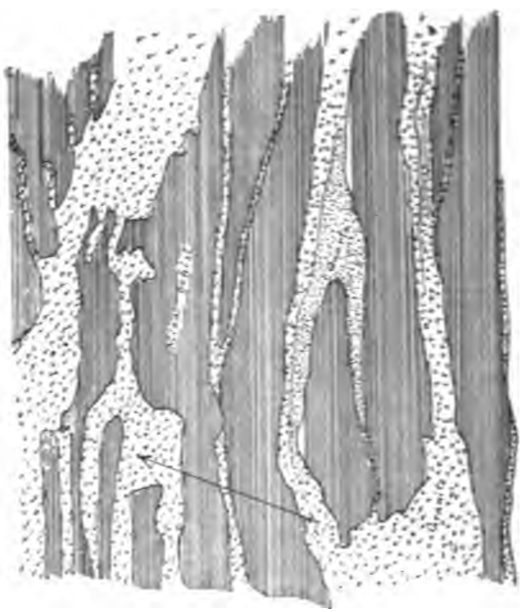

FIGURE 2.—*Relations of Mica Schist and Gneiss, Burntside Lake* (*surface* 12 *feet square*).

crossed, though it did not exceed three hundred feet in breadth. This was made up of alternations of rigidly parallel and indefinitely extended bands of uralitic schist and a gneissoid rock. These became, in one part of the belt, so slender that I estimated that five hundred alternations occurred within the space of fifty feet. This would give but an inch and two-tenths for the mean thickness of each. But many of them were thicker than this, while many others were attenuated to a thickness of half or a quarter of an inch. And yet each preserved a rigid continuity of direction.*

The structural relations of the granitoid, gneissoid, and schistoid rocks

* *Sixteenth Ann. Rep. Minn.*, pp. 263–264.

present also a phase somewhat different from that which we have been contemplating. In a multitude of cases the schistic fragments are separated by an irregular fracture from the parent mass, and, though their original alignment with its bedding planes is not impaired, it becomes evident that the intervening gneiss is not strictly an interbedded sheet. See fig. 2.*

In other cases the schist is more thoroughly disrupted, and the gneiss loses its foliation and assumes a distinctly granitoid character. It insinuates

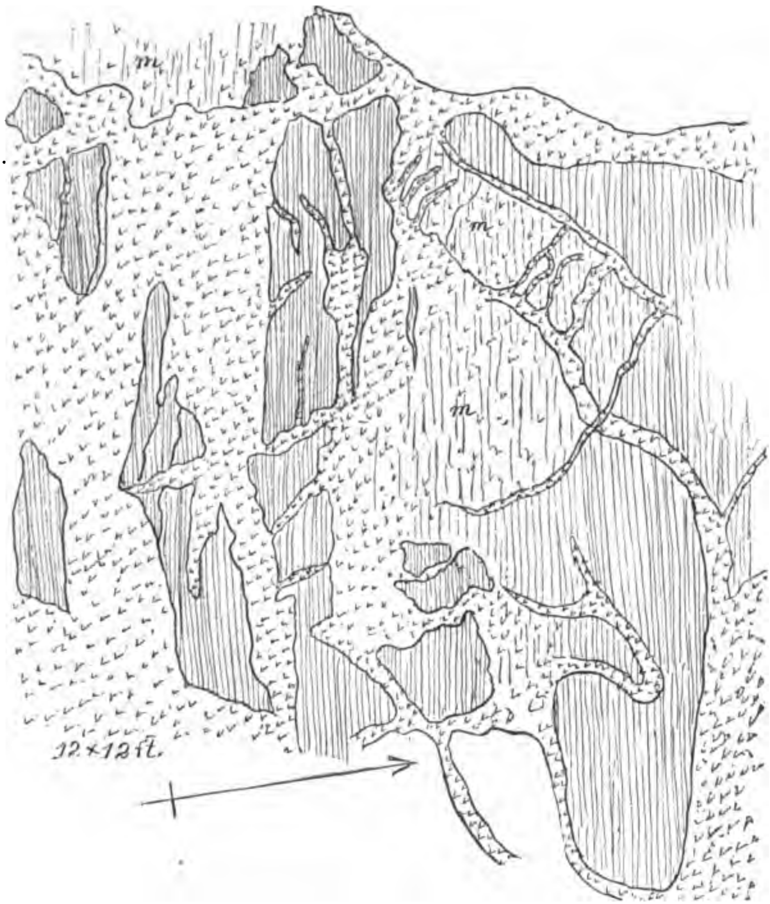

FIGURE 3.—*Relations of Muscovite Schist and Granite, Burntside Lake.*

itself into narrow fissures and begins to cut the schists in many directions, presenting the aspect of true granitic veins. See fig. 3.†

In the regions marked *m* the schist and granite are intimately mixed.

* See also fig. 33, *Fifteenth Ann Rep. Minn.*, p. 290; and fig. 14, "Relations of crystalline rocks at Pelican Lake," *Sixteenth Ann. Rep. Minn.*, p. 451.

† See further fig. 30, *Fifteenth Ann. Rep. Minn.*, p. 78; fig. 53, *Sixteenth Ann. Rep. Minn.*, p. 295; and fig. 12, *Sixteenth Ann. Rep. Minn.*, p. 447.

Speaking of the south shore of Rainy lake, Mr. H. V. Winchell remarks:

"The schists lie against the gneiss along the coast. They are mixed and cut and twisted up together in a remarkable fashion. Long feelers of the gneiss or granite stretch off through and across the beds of schist, and from them branch out smaller, winding, twisting veins in all directions." *

We discover evidences of interactions still more energetic. In numerous cases we have observed fragments of gneiss or syenite inclosed in the body

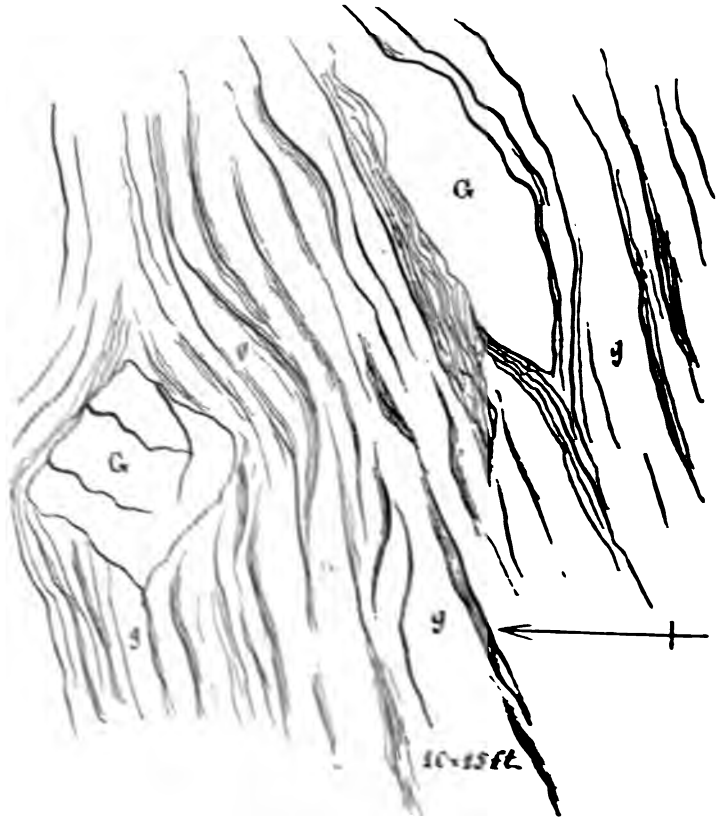

Figure 4.—[illegible] Basswood Lake.

of the schists. See fig. 4.† The dark bands represent schists; the light spaces between, g g g, are gneiss; detached and included masses are seen at G G [illegible] with veins.

A curious instance is found on Rainy lake.

[illegible] considerable length are not [illegible] and in fact all shapes

* [illegible]

† [illegible] Ann. Rep. Minn., p. [illegible]

and sizes, of mica schist are seen in the gneiss where the gneiss predominates, and of gneiss in the schist where the schist is the main rock." *

In some instances a mass of syenite inclosed in schist holds in itself fragments of schist, as in fig. 5. In many cases also the schistic beds wrap

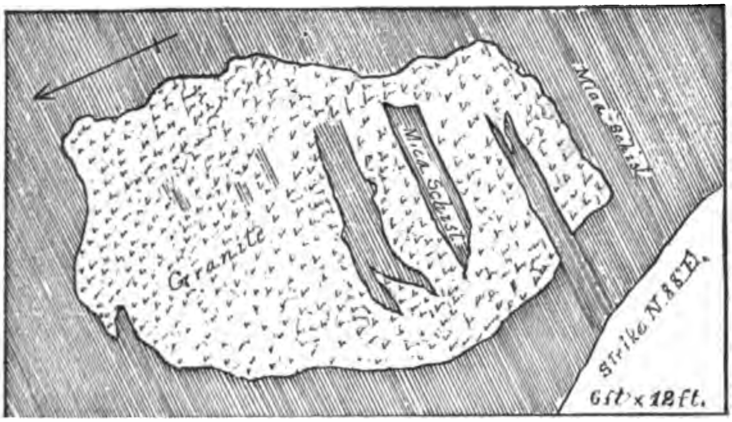

FIGURE 5.—*Schist inclosing Granulite, itself embodying Mica schist, Burntside Lake.*

around the gneissic fragments, indicating that the fragments were introduced while the schist was in course of formation; and indicating, too, that the gneiss had been already consolidated when the schist was forming (see fig. 6†). In very many of these cases the gneissoid fragment has been bent in

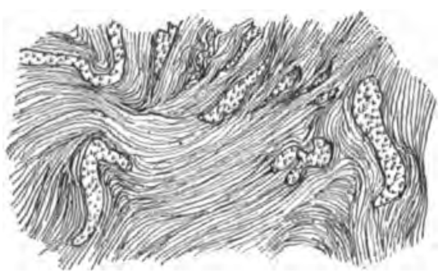

FIGURE 6.—*Hydromica Schist wrapped around Masses of Granite, Farm Lake, Minn.*

a marked degree and shaped to the enwrapping schist. This seems to show that the consolidated gneiss had been rendered plastic again.

Sometimes the schists appear intertwisted without the presence of gneissic fragments.‡ Sometimes the included fragments are quartzitic, and the mutual actions are the same.§ These phenomena indicate some relative

* H. V. Winchell, *Sixteenth Minn. Rep.*, p. 428.
† See further illustrations, fig. 36, *Fifteenth Ann. Rep. Minn.*, p. 89; Ibid., fig. 38, p. 97.
‡ This is illustrated in figs. 40 and 42, *Fifteenth Ann. Report Minn.*, pp. 111 and 116.
§ *Sixteenth Minnesota Report*, p. 409.

movements of the two masses of rock material. But there is no evidence of any other than very slow and gentle movements. It would appear that the plasticity evident in the included gneissoid fragments extended, also, to the schist, though in a less degree. Nothing appears to prove whether the gneissoid fragments were introduced during the sedimentary deposition of the pre-schistic beds—the layers of soft sediments adapting themselves to the introduced masses; or were thrust into the body of schist after consolidation and re-softening—the layers of schist adjusting themselves to the foreign bodies. There are, however, no traces of lines of travel through the schists, indicating that the fragments had reached their position through some passage opened from the place of entrance into the schists. Their environment is as uninterrupted and close as if the fragments had been original enclosures.

Phenomena of the class cited above have not been very widely recorded. But they are not unknown. Dufrénoy and Élie de Beaumont have described the *massif* of central France as composed almost entirely of granite and gneiss, the "latter passing up into mica schists and downward into fine-grained granite, with which it alternates."* Alternations of granites and gneisses have also been described from America † and other countries. M. A. Michel-Lévy, in discussing the crystalline rocks, speaks of these interbeddings as somewhat familiar.‡

MINERALOGICAL RELATIONS OF THE GRANITOID, GNEISSOID, AND SCHISTOID ROCKS.

Throughout the Northwest it is difficult to distinguish recognized gneiss from recognized schists of the mica and hornblende bearing sorts by any mineralogical character except its larger percentage of feldspar.§ It is true that the gneisses are generally coarser and heavier bedded, but they are not always so. It is true that the schists occupy on the whole a different horizon; but I find them frequently in the same horizon. When I examine closely the characters of the constituent minerals I find nothing about the quartz, nor the micas and hornblendes, nor the feldspars by which I can say that a given character belongs rather to the gneisses or to the schists.‖

* Expl. Carte Géol. de la France, vol. i, 1841, p. 109; Prestwich, *Geology*, vol. i, 1886, p. 421.

† See, for instance, King, *Fortieth Parallel Survey*, vol. i, 1878, p. 102.

‡ Speaking of intercalations in the acidic gneisses, he says: "Ces intercalations sont toujours parallèles à la schistosité. * * * Les gneiss acides et de plus en plus cristallins dominent à la base; puis ils admettent des intercalations fréquentes de micaschistes et de leptynites, auquels s'associent de nombreux délits d'amphibole et de cipolin." *Note sur l'origine des terrains cristallins primitifs.* Bull. de la Société géolog. de France, 2 Nov., 1887, p. 103.

§ This fact has been noted of other regions. King says: "The crystalline schists and gneisses are formed of identically the same anhydrous minerals which characterize the granites. * * * Granite possesses the same minerals, and, furthermore, their microscopical structure and the character of their foreign inclusions are identical." King, *Fortieth Parallel Survey*, vol. i, 1878, pp. 117–118.

‖ This is meant rather for a provisional than a final statement. M. A. Michel-Lévy has enumerated microscopic characters by which he thinks the crystalline schists differ from the gneisses. *Op. cit.*, p. 106.

Furthermore, the facts which I have cited in reference to the interbedding of gneisses and schists show that, while each stratum retains a characteristic individuality, this is something which depends, first, upon relative richness in feldspar, and, second, upon the coloration and relative proportions of the other two essential constituents. The very facts of the geologically rapid alternation of gneiss and schists argues the persistence of the same petrogenic forces and their indifference to the relative proportions of feldspathic elements. It is easy to believe, however, that some change in addition to that of the supply of material takes place when the formation becomes schistic, and that an æonic change may be conceived as inaugurating the formation of the great body of the crystalline schists; but, as I am here dealing only with observed facts, I repeat, no mineralogical alternations are found in the zone of lithological alternations except the changes in the proportions of feldspar.

The indifference of Nature to a greater or less proportion of feldspar is indicated by the fact observed in some cases that in the local passage from the schistoid to the gneissoid phase the schistoid aspect melts into the gneissoid, and the resulting rock is simply the product of their interblending.

The facts stated in these paragraphs have been with me the subject of common observation; but the conclusion which I base on them is decidedly in conflict with prevailing opinion; and I shall make a few citations from the recorded observations of other geologists upon similar rocks. At a certain locality on the Little Fork river, Mr. H. V. Winchell describes the situation as follows:

"Just below, around the point, is an outcrop of mica schist interbedded with thin beds of gneiss. * * * It [the schist] is quite thin bedded and is the characteristic rock of this whole region. In places it is hard to say which is schist and which is gneiss or where one bed stops and the other commences, and, again, they are separated quite distinctly." *

Speaking of a locality on the south shore of Rainy lake, the same observer says:

"In the southwest quarter of section 25, in the same township [71-23], this diabase has all graduated into a rock that is very plainly gneiss, and, going a little farther south across the strike, it is still farther changed into a thin-bedded gneiss and finally into mica schist with the ordinary strike and dip." †

Of the occurrence at another point on Rainy lake the same authority reports:

"At this place is a bed of gneiss that cuts across the schist for some distance, then comes into conformity with it, and all at once splits up into thin beds an inch or two thick and becomes lost in the schist." ‡

* *Sixteenth Ann. Rep. Minn. Surv.*, pp. 405-'6.
† Ibid., p. 415.
‡ Ibid., p. 419.

Similarly, Dr. Lawson observes:

"In some of these lenses the interfusion of matrix and inclusion has been so complete that they are entirely made up of this transitional rock, which has the facies of a syenite."*

Describing the rocks of the Lake of the Woods, he says:

"It is not uncommon to find in these mica schists a small proportion of feldspar, which gives them the character of finely laminated gneisses, in places."

Referring to the north shore of Vermilion lake, State Geologist N. H. Winchell says:

"This schist has a very evident sedimentary structure. It is firm and even shows an approximation to gneiss, the foliation of which is then the same as the bedding structure of the schist. When, however, the gneissic structure comes on, the grains are finer than in the schist, the color is darker, but the striping due to sedimentation is still preserved."†

I quote again from Dr. Lawson:

"On the south shore of Rainy lake, near Coutchiching rapids, there is in association with the mica schists an iron-gray micaceous gneiss, differing from the former only in the possession of a feldspathic constituent. It might, perhaps, be rather called a feldspathic mica schist than a gneiss."‡

"The rocks of the Rice Bay Area [Rainy lake] of the Coutchiching series [mica schists] differ somewhat from those of the same series farther south. They are, as before, all very quartzose and fall into two varieties, those containing feldspar and those free from it. * * * In the feldspathic variety * * * the rock assumes the form of a gneiss of peculiar character. * * * In these rocks orthoclase occurs sometimes in large crystals from half to an inch across. * * * There is a considerable proportion of feldspar associated with the quartz throughout the rock. The schists or gneisses, in which the augen-like feldspars were observed, are in proximity to the very coarse mica-syenite or syenite gneiss on the south side of Hopkins bay, which appears to be of irruptive origin."§

This same rock, so gneiss-like that Dr. Lawson scarcely knows whether to call it gneiss or schist, is described on the following page as "an eminently granulitic aggregate. * * * The granulitic or rounded character of the grains is, however, characteristic only of the quartz and orthoclase, while the plagioclase often presents irregular or granular shapes."

From an island in Rainy river he describes a rock which "has the aspect of a very fine-grained gray gneiss of even lamination, * * * but is found to be made up wholly of quartz with a little plagioclase. * * * The rounded shape of the constituent grains of quartz appears to be due to water-wearing action in an original sand."||

* *Annual Report Geol. Surv. Canada*, 1888, p. 137F.
† *Fifteenth Minn. Rep.*, p. 299.
‡ Ibid., p. 188F.
§ Ibid., p. 110F.
|| Ibid., p. 111F. Compare also pp. 140–'1F.

It seems to me that the facts here cited, with a great multitude of others of similar tenor, render it necessary to unite the gneissoid and schistoid rocks under one petrographic mode of derivation. They are so inseparable on any fundamental grounds and are so blended together, both structurally and mineralogically, that no reasons appear to exist for a reference of one class to a mode of origin fundamentally different from the mode of origin of the other class. On this question, however, I only propose at present to cite some observed facts. The interpretation of them may be subsequently undertaken.

AREAS OF SEMI-CRYSTALLINE SCHISTS.*

The crystalline schists are succeded by a system of semi-crystalline schists. They range, however, from fragmental crystalline to earthy. They succeed in perfect structural conformity with the older schists, with only slight indications of stratigraphic disturbance. Their attitude is generally vertical or steeply inclined. Their position is between and surrounding the gneissoid areas. In northeastern Minnesota their position is between the elongated Basswood Area on the north and the elongated White Iron Area on the south. The belt, therefore, holds a persistent strike for seventy miles. In this region it is not revealed as an encircling belt, because the southern half of the White Iron Area is covered by gabbro and the northern border of the Basswood Area remains uninvestigated; but the Saganaga Area is bordered on the northwest, west, and south by these schists, and the belt passing on the south side has been traced along the north side of Gunflint and North lakes and has been identified as far east as South Fowl lake, in the third range of townships east of the Minnesota meridian, twelve miles west of Grand Portage. In the Vermilion Granitoid Area, however, the strike of the semi-crystalline schists is circumferential. On all the sides the dip is steep and it diminishes from all directions toward the centre. This is the arrangement of these schists around the borders of the numerous granitoid areas occurring in the region of Rainy lake and Lake of the Woods.

In each of the intervals between neighboring granitoid areas the semi-crystalline schists present the structure of a simple synclinal fold. This is close-pressed along the axis, and the strata are accordingly vertical. Proceeding toward the centre of the granitoid area, the dip in the majority of cases being always toward the synclinal, becomes less steep. The granitoid

* These, with the crystalline schists included, were named "Keewatin series" by Dr. A. C. Lawson in his report of 1886, pp. 10–15. Subsequently he separated the crystalline schists under the name "Coutchiching series" (*Amer. Jour. Sci.*, 3d Ser., vol. 32, 1886, p. 477.) The name Keewatin has been employed by the Minnesota Survey in the sense thus restricted, but the term "Vermilion series" was already in vogue before Dr. Lawson's separation of the crystalline schists. As the spelling of Chippewa names can scarcely be regarded as fixed by any literary or scientific authority, unless it be the usage of ethnographers, I suggest that the useless second "e" be dropped from the name employed by Lawson, thus making it "Kewatin" (pronounced Ke-way-tin). An orthography better supported by linguistic ethnology would be Ki-we-tin.

area, therefore, is essentially dome-shaped, and the crystalline and semi-crystalline schists appear to have once extended over the dome and to have been subsequently denuded (fig. 7). In some cases the proximate verticality of the structure persists to the middle of the granitoid area and quite across it. We must, nevertheless, conceive the middle of the area as the position of an anticlinal axis or point.*

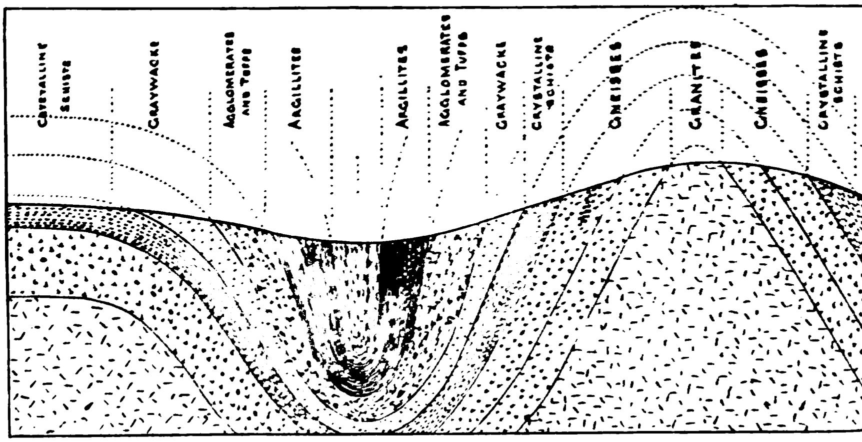

FIGURE 7.—*Plan of the Folding of the Crystalline and Semi-Crystalline Rocks in the Northwest.*

Occasionally the single synclinal becomes two or perhaps three with partial anticlinals intercalated.

It will be inferred from the structure described that a traverse from side to side of the semi-crystalline zone exposes the members of the series in direct and then in inverted order and gives twice its total thickness. Similarly a traverse across the area of crystalline schists and gneisses presents the succession in direct and inverted order and gives twice the exposed thickness of those terranes.

THE LITHOLOGICAL CONSTITUTION OF THE SYSTEM OF SEMI-CRYSTALLINE SCHISTS.

The lithology of this system is obscure, anomalous, multifarious, and without parallel in any other part of the earth's crust. It is essentially a system of bedded rocks, but they are cut by numerous basic eruptives. The beds are mostly clastic, but in places they present the aspect of decayed diabasic sheets. Certain beds unequivocally fragmental in one locality pass along

*This plan of folding of these schists was announced in my Report of observations for 1886 (*Fifteenth Minnesota Report*, p. 192); and also by Dr. Lawson in his Report on the Lake of the Woods in 1886 (p. 107cc). But he seems to detect evidences, in some cases, of two or three synclinals in the width of the belt. This may easily be so without any change in our conception of the mechanics of the rocky structure.

the strike to beds petrosiliceous, felsitic, and pseudo-diabasic. A terrane bearing the characters of an argillite passes in one direction into a siliceous schist and in another acquires felsitic or serpentinous matter until it arrives at the stage of a petrographic nondescript, which I have called "porphyrellite," but which approaches somewhat to Hunt's "parophite." The same terrane passes on one side into an obscure conglomerate and on the other into a porphyroid condition, sometimes with pebbles added. In this system are formations which may be styled volcanic tuffs, often light colored, with imbedded angular fragments blending with the groundmass, often agglomeratic and nondescript.

It is evidently beyond the scope of this paper to furnish an elaborate account of these rocks, but I will endeavor to enumerate their leading stratigraphic aspects.

Argillite is one of the most persistent terranes. Its centre of characteristic development in the trough between the Basswood and White Iron granitoid areas is in the region of Moose and Newfound lakes, in the ninth range of townships west of the Minnesota meridian. It is here prevailingly russet, handsomely cleavable in immense vertical sheets, and strictly argillitic. In places, both eastward and westward, it assumes a slaty color. On Ensign lake, to the northeast it, becomes sericitic, and the same variation is wide-spread westward, about Eagle-nest lakes. In both directions it sometimes takes a greenish, chloritic-sericitic character. As far west as Tower it becomes rather characteristically a sericitic schist, and it is in this that the great deposits of hæmatite occur. At a few localities on Ensign lake the soft sericitic argillite contains a great abundance of quartz grains, and this character reäppears 18 miles father northeast, on Frog-rock and Town-line lakes. The same feature is widely distributed in the vicinity of Vermilion lake.* North and northeast of Ensign lake, on Sucker lake, and at the west end of Knife lake it becomes siliceous and in places is simply a black siliceous or flinty schist, here as everywhere standing on edge. In the more exact direction of the strike it continues to Ogishke-muncie lake and along both shores of this lake; and throughout the vicinity this argillite undergoes a remarkable modification by the inclosure of long-extended series of pebbles and bowlders, forming what we know as the Ogishke conglomerate.† It is to be remarked in this case that the slaty beds do not curve around the bowlders. On the north and west of the lake the matrix of the conglomerate preserves well its slaty character, but on the south it has been altered to a silico-diabasic aspect. In this state the pebbles are inconspicuous, but they may be distinctly seen on smoothed surfaces under water. This condition also exists on Crab lake and the northwest part of Frog-rock lake. The bowlders and pebbles of

* *Fifteenth Minn. Rep.*, p. 20.

† This conglomerate, in the judgment of my brother, is embraced in the Animike formation. *Fifteenth Minnesota Rep.*, pp. 91, 97; *Seventeenth Rep.*, pp. 17, 47. My views and reasonings are given in the *Sixteenth Rep.*, pp. 344–350, 259–360.

this conglomerate are derived from crystalline rocks, being largely granulitic, gneissic, and quartzose, and they lie imbedded so firmly that fractures of the rock pass equally through them and the matrix. This matrix generally is a good, but often siliceous, argillite, dark, or inclining to greenish, with cleavage coincident with the sedimentary bedding.

No other occurrence of the Ogishke conglomerate is at present known in Minnesota, but Dr. Lawson has shown that it recurs on Rainy lake, at Rat Root bay, and also on Grassy and Shoal lakes,* where similar pebbles are imbedded in a fissile, glossy, green, chloritic schist. Seventy-five miles northeast of Ogishke-muncie lake, in the vicinity of Thunder bay on Lake Superior, occur vertically-standing conglomerates of exceedingly similar character. I quote from the Report of Sir William E. Logan:

"Rising in the series [superjacent to the gneisses] the dark-green slates become interstratified with layers holding a sufficient number of pebbles of different kinds to constitute conglomerates. The pebbles appear to be all derived from altered rocks. They vary greatly in size in different places and occasionally measure a foot in diameter. Where the slate conglomerates have been worn by the action of water, the pebbles are generally worn down equally with the rest of the surface, and, though a very distinct picture of them is presented on such a surface, * * * it yet often happens, unless the pebbles are of white quartz, that they are very obscurely distinguishable on fracturing the rock, both the pebbles and the matrix having a gray color and showing very little apparent difference in mineral character. * * * The rock has nowhere on the lake been observed to display true slaty cleavage independent of the bedding." †

These are characters of the Ogishke conglomerate. The only difference is a more greenish color of the slates. The same conglomerate is exposed at other points on the shore of Lake Superior. A voluminous outcrop is noted at the mouth of the River Doré, where seventeen hundred feet are described as green slate rock in vertical attitude, striking east and west and presenting sometimes ribboned edges of green, black, red, and gray and mostly charged with crystalline pebbles and bowlders firmly imbedded. "Toward the lower part it assumes more the character of the gneiss which usually succeeds it." ‡

In the region of Dog lake, north of Thunder bay, the slates which elsewhere are greenish and conglomeratic are described as "dark greenish blue or greenish black slates, passing downward almost imperceptibly into a hornblendic gneiss." §

I direct particular attention to this eastward extension of dark and greenish slates, densely conglomeratic, at intervals, as far as the eastern shore of Lake Superior.

* *Canada Report*, 1888, Doc. F, pp. 55-'6, 82-'4.
† *Geology of Canada*, 1863, pp. 52-53.
‡ *Geology of Canada*, 1863, pp. 53-54.
§ *Geology of Canada*, 1863, pp. 64.

Altered Tuffs and Mixed Rocks.—Though the argillites and their included conglomerates are the most bulky and conspicuous member of the semi-crystalline schists, they are not the most characteristic feature of this system. Immediately eastward from Tower the proper argillites have a feeble development, and they seem to be partially replaced by sericitic and chloriotic argillites and sericitic schists, and the same conditions are found at many places eastward as far as Ogishke-munice. But in the vicinity of Vermilion lake certain clastic rocks represent very imperfectly the character of sericitic schists. The transition from these to true schists is, many times, along the line of strike, but it is also sometimes across the strike. These nondescript rocks, when well developed, have often been designated "porodite" by the Minnesota Survey. They are generally ashen colored, mostly fine textured, generally rather soft, but with disseminated quartz grains, which sometimes attain dimensions of a quarter of an inch, and they show obscure tracings on weathered surfaces, suggesting an original conglom eratic or agglomeratic constitution. They have only very obscure lamination. Beds answering such a description are extensively interstratified with characteristic schists. There are also occasional beds of this character which cut, dike-like, at a small angle across the strike of the graywackes. These probably, though similiar, have had a different origin. It seems to be a rock allied to this porodite, which in places contains small quartzose and granitic pebbles, and constitutes the "Stuntz conglomerate," which, but for other evidence, might be regarded as occupying the horizon of the Ogishke conglomerate.

Porphyrellite.—The porodite of Vermilion lake holds lumps of serpentine, and the recognized sericitic and chloritic schists are sometimes serpentinous. These appearances increase eastward. It does not appear that the magnesian formation is developed at the expense of the argillitic, though it is certain that the magnesian character is sometimes superinduced on an argillitic foundation. At Sucker lake, on the boundary, certain schists having a serpentinous aspect begin to abound. This is in a zone somewhat north of the argillites and nearer the granitoid rocks of the Basswood area, and therefore regarded as underlying. At Sucker lake these rocks possess a greenish, argillitic aspect, but their edges transmit light, and the hardness and feel are slightly magnesian. Traced to the eastern ramifications of Knife lake, this formation attains an imposing development. It may, under some of its aspects, answer to the "parophite" of Hunt, but I have called it, for the purposes of description, "porphyrellite." The formation is unquestionably bedded, but it is often imperfectly so, and it is intersected by a multitude of irregular local fissures making acute angles with the bedding and with each other and converting the rock sometimes into an infinite number of small cuneate and lenticular forms closely packed together.

This remarkable and important formation presents graduations in many directions from the typical state, but the scope of this paper permits no more than a mere enumeration: 1. It graduates into slate-colored argillite, both along the strike and across it. 2. It often develops whitish, obscurely outlined crystals of feldspar. These are found in all stages of development from incipient visibility onward. This condition I have called "porphyrel." 3. The formation sometimes contains distinctly outlined, rounded pebbles, especially on the remote arms of Knife lake. The pebbles are sometimes present with the porphyritic structure. 4. The formation also, at times, develops grains of quartz, and on the north of Gunflint lake both quartz and feldspar. 5. It graduates into the green schists, which possess exactly the same structure and aspect with a greenish color and diminished translucency. These are the "Kawasachong" or "Kawishiwin" rock, by some regarded as a decayed diabasic rock. 6. It graduates into a graywackenitic rock with fine granular quartz and feldspar in an argillaceous base. 7. The graywackenitic rock assumes a larger proportion of silica and becomes something like hornfels. 8. The formation acquires felsitic matter and becomes a good felsitic schist, and this is quite extensively developed. 9. Through this stage it passes into a silico-diabasic slate, a protean formation truly of which still much remains to be learned. The essential ingredient is widely disseminated in this system of rocks and can often be detected in gneisses and other petrographic conditions not otherwise affiliated with porphyrellite. Thus disseminated I have called it "Kewatin stuff."

Graywacke.—As nearly as I can judge, very little typical graywacke exists in this system of rocks, but the name has been much used, and the condition to which it is applied approximates conformity to the accepted definition. It is composed of small water-worn grains of quartz and feldspar, imbedded in an argillaceous groundmass, with minute mica scales and particles of a black substance, and generally some silica chemically combined; but from this state is passes into a siliceous hornfels and a quasi-diabasic state, and, on the other hand, graduates into a massive argillitic rock.

The graywacke holds position next to the crystalline schists, but it is not everywhere present in its place. Next to the graywacke, as nearly as I have ascertained, comes the poroditic and porphyrellitic formation, with its numerous phases. Next higher in the series occur the argillites, with their heteromorphs, and the sericitic schists, while near the centre of the folded synclinal occur the beds of hæmatite. In a tentative way, therefore, I would arrange the members of the system of semi-crystalline rocks in the following manner:

4. Sericitic schists inclosing beds of hæmatite.

3. Argillites and the included Ogishke-muncie conglomerate, with lenticular masses of dolomite.

2. Porphyrellite and chloritic schists and other conditions into which they graduate; also the porodites, agglomerates, and tuffs of nondescript character.

1. Graywackes.

(Underlain by hornblende and mica schists.)

In his description of the corresponding system of rocks on the shores of the Lake of the Woods Dr. Lawson groups them as follows:

"Felsitic, sericitic, and other glossy fissile schists of a hydromicaceous or chloritic character, with some carbonaceous schists and limited occurrences of limestone.

"Mica or hydromica schists, clay-slates, and quartzites.

"Hornblende schists, with associated trap rocks, principally altered diabases and diorites." [Afterward excluded from the Kewatin.] *

In the vicinity of Rainy lake he gives:

"Felsitic schists (quartz porphyries and their tuffs) and agglomerates.

"Altered traps and green hornblendic schists." †

Dr. Lawson's hydromica schists are my sericitic schists. His agglomerates are embraced in my No. 2, and so, I think, are some of his felsitic schists. While the general character of the rocks studied by him is plainly the same as that of the rocks described by the Minnesota Survey, the correlations in detail have not yet been completed.

The approximate thickness of this system of rocks in Minnesota, as deduced from four sections between the Basswood and White Iron Areas, is about 15,000 feet. In the Rainy lake region Dr. Lawson has calculated thicknesses of 10,200 and 13,200 feet.

Structural and Mineralogical Relations of the Crystalline and Semi-Crystalline Schists.

Wherever the crystalline and semi-crystalline schists are seen in juxtaposition their stratification is strictly conformable. Wherever the crystalline schists are wanting, the semi-crystalline schists are found in conformity with the gneisses. Moreover, whether the semi-crystalline schists occur in juxtaposition with the crystalline schists or the gneisses, there exist frequently those transitions by alternation which characterize the passage from the crystalline schists to the gneisses. This mode of transition, however, is much the most characteristic of the passage from the semi-crystallines to the crystallines; but this passage is simultaneous with mineralological changes which must also be mentioned.

It was early remarked that the Minnesota graywackes contain always some proportion of fine mica scales. As we descend to the neighborhood of

* *Canadian Geological Report*, Doc. CC, 1886, pp. 12, 29, 106, etc.
† *Canadian Report*, 1888, Doc. F, p. 46.

the mica and hornblende schists the proportion of mica scales generally increases, and in some states the graywacke has much the aspect of a fine, earthy mica schist. The appearance suggests that we have a rock in which the mica element is just emerging into existence from some magma or is checked in its emergence before attaining full development. This is what I have frequently denominated "nascent mica schist." It answers the description of the "tender mica schists" which characterize Hunt's "Montalban series," which, so far as I know, may occupy nearly the same horizon. Quite a development of this formation occurs about the north end of White Iron lake.

In the passage downward from nascent mica schist to the truly crystalline schists, we sometimes arrive at a stadium in which minute and obscure developments of both biotite and hornblende may be detected. One almost fancies the primitive ground material to have been in a condition of petrogenic equilibrium. The impression is deepened by noting the predominance of biotite at one point and the predominance of hornblende at another, almost in the same hand specimen. These zones of doubtful supremacy are narrow. In the immediate vicinity, some older bed reveals the presence of characteristic biotite schist or hornblende schist.

At many points the transition from the semi-crystalline to the crystalline schists is made without the intervention of graywacke. A very noteworthy instance of this occurs on the north shore of Gunflint lake,* where the vertical porphyrellitic argillites approach the gneissic area. At several points on the lake shore the rock is observed to develop the feldspar crystals which characterize porphyrel. Occasionally it develops quartz grains instead, and constitutes what is described near Vermilion lake as "porphyritically quartzose porodite." In the transition belt here alluded to this condition of the rock receives also occasional dun or dark structureless patches. These, farther on, assume a uralitic aspect and then a hornblendic aspect, and out of them emerge, in zones still nearer the gneissic area, sometimes uralitic hornblende individuals which, with quartz and feldspar already present, give a uralitic gneiss. Sometimes also the dark patches develop mica, and in such case the ultimate formation is a good gneiss. The ground material gradually diminishes and finally ceases to appear.

A variation of the mode of transition may be seen at the same locality. In this is an intervention of uralitic schist. The semi-crystalline schist begins as a sericitic or porphyrellitic argillite. It then becomes porphyrel, growing harder and more crystalline. Next, the feldspar is seen to weather reddish, while the rock has a syenitic look. Still farther toward the gneissic area the formation is banded by belts looking like hornblende schist; but the hornblende is still of argillitic softness, and there are fine glistening

* *Sixteenth Minnesota Report*, pp. 262–265.

scales appearing like sericite, but in places recognizable as mica. Here, then, are alternating sheets of porphyrel and crude uralitic and micaceous schist. Now appear very thin laminæ composed of feldspar, a hornblende-like mineral, and ten per cent. of quartz. These continue to alternate with the porphyrel. The alternations become exceedingly frequent, but the uralitic bands increase in breadth, and the whole terrane finally becomes a uralitic gneiss, and soon after reveals the coarse quartz individuals of the well-known Saganaga gneiss.

It is hardly necessary to remark that the transitions mentioned are simply progressive in a geographical sense. The historical or genetic succession may have been the reverse, or the whole work may have been simultaneous.

Thus far the older rocks of the Northwest have presented a condition of strict structural conformity. This fact was long unsuspected by American geologists, but no field geologist of the Northwest entertains on this subject the least doubt. What is even more striking is the gradual transition and mutual blending witnessed in the passage from one of the systems enumerated to the contiguous one. The facts provoke many theoretical inquiries; but I will only state that I do not regard the universal conformity of stratification as evidence of the absence of geological breaks.

The Uncrystalline Schists.

On the north side of Gunflint lake the vertical schists are found overlain by schists extremely different in character and attitude. They are nearly horizontal, having a dip here of only about five degrees south by east. They undergo a great development in northeastern Minnesota. They have been traced westward well toward Ogishke-muncie lake. Eastward I have traced them to Partridge falls on Pigeon river. Between the national boundary and Thunder bay they have been reported by Dr. Robert Bell, of the Canadian Survey,* and on Thunder bay and in its vicinity they have been described repeatedly by the Canadian observers. They constitute the "Animike series" of Hunt, and by that name I shall for the present refer to them. In Minnesota this is strikingly a thin-bedded, black argillitic series, rising in high bluffs along the south sides of the lakes and generally crowned by twenty-five to seventy-five feet of semi-columnar gabbro. These characters present themselves at all outcrops as far as Thunder bay. Certain strata, not very definite in position, receive disseminated grains of quartz, and the formation thus approaches a proper black graywacke. Within this system other strata, more definite in position, acquire a siliceous character, and some become strictly beds of flint and jasper schist. Some of these are brilliantly red or deep black, smoky, yellow, or chalcedonic. The

* *Report for* 1866–'9, p. 322.

formation also embraces heavy beds of magnetite. More correctly, certain beds become richly magnetitic, and within limited districts are dense granular magnetite, nearly pure, and from two to four feet thick. About Gunflint lake the argillites contain occasional pebbles and even become conglomeratic;* but about Thunder bay they become well-developed conglomeratic slates, and have been described as "slate conglomerates" and referred to the lower member of the Upper Copper-bearing series.

The characters of the Animike series are so generally understood that I shall offer no further stratigraphical details in this place. Professor Irving was acquainted with these rocks in their eastward extension; but he strangely

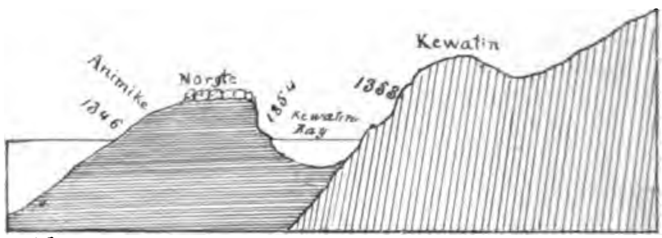

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FIGURE 8.—*Contact of the Animike and Kewatin Schists on the North Shore of Gunflint Lake.*
This is the only point on the lake where the Kewatin comes to the shore.

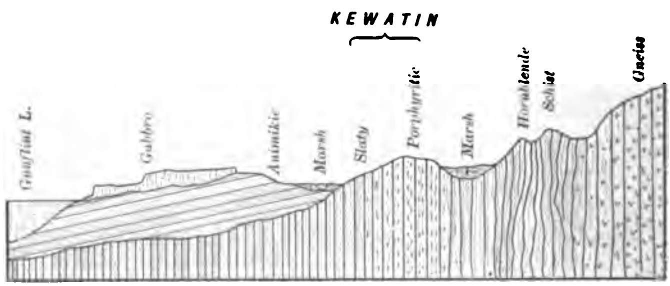

FIGURE 9.—*Relative Positions of the Animike and Kewatin Schists as seen on a Traverse North of Gunflint Lake.*

Showing junction of the two systems and transition from Kewatin through crystalline schists to gneiss. Vertical dimensions exaggerated, as usual.

identified them with the system of semi-crystalline schists. He was quite aware of the great difference in attitude of the two; but he argued that perhaps their outcrops were located on opposite sides of a granitoid area, the uplift of which had tilted the schists to a greater extent on one side than the other. He makes no mention of the discovery of an actual contact, with the two dips brought into immediate juxtaposition. He reports, however, an increased dip of the Animike schists in approaching Gunflint lake

* *Sixteenth Minnesota Report*, pp. 103, 107.

from the east. This is a fact which I have observed, but it is a local phenomenon, and the normal flat-lying position is soon resumed.* I shall therefore demonstrate that the Animike system is not one with the semi-crystalline system. The nature of the observed contact on the north shore of Gunflint lake is illustrated in the accompanying diagrams, made on the spot. Here are the two systems assumed by Irving to be identical, and to have different dips in consequence of the remoteness from each other of the portions compared (figs. 8, 9, 10). If you trust me for a correct statement

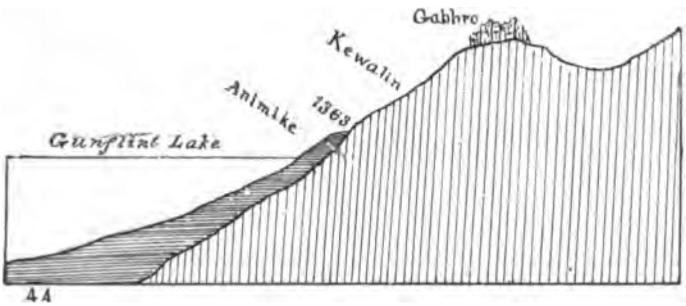

FIGURE 10.—*Observed Contact of Animike and Kewatin north shore of Gunflint Lake.*

of the facts you cannot regard the semi-crystalline schists and the uncrystalline schists as both Huronian.†

I will here recall a diagram published by Professor Irving in an elaborate memoir read before the National Academy of Science April 22, 1887, and published in the *American Journal of Science* for September, October, and November, 1887. The figure is given at page 261.‡ The first impression is that he intended to represent the same state of things as I have shown. If

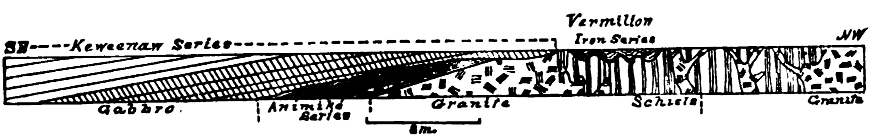

FIGURE 11.—*Professor Irving's "generalized and partly idealized section of the northeastern part of Minnesota."*§

so, one would suppose that he knew nothing of it by personal observation. The interpretation shows that he misconceived his own figure. The verti-

* *Compare Seventeenth Annual Report Minnesota*, 1888, p. 47.

† I published these facts originally in the *American Geologist* for January, 1888, Vol. I, pp. 14–24 They appear with amplification in the *Sixteenth Annual Report of the Geol. and Nat. Hist. Surv. of Minnesota*, 1887, pp. 256, 259, 264, 357–'8. The first announcement of the facts was made in the *Amer. Jour. Sci.*, Oct., 1887, 3d Ser., Vol. xxxiv, p. 314—the communication being dated Aug. 29, 1887.

‡ The figure and the entire exposition of the relations of the Animike and the older schists are. reproduced in the "Seventh Annual Report of the Director" of the U. S. Geological Survey, 1885–1886. Printed 1888; received April 23, 1889.

§ This is his "generalized" illustration, and is here chosen because, in addition to the unconformity, it explains Professor Irving's theory (or hypothesis) respecting the way in which the Vermilion iron ores exist in the Animike.

cal schists he refers *as a whole* to the system of crystalline schists. It is thus very easy to make the horizontal schists answer for the next overlying system above the crystalline. But the truth is that only the vertical schists at the right or north of the diagram represent the crystalline schists and gneisses, while those at the left of these, quite conformable in their verticality, are the semi-crystalline schists. (Compare figure 9, above.) These prolonged to Vermilion lake contain the great hematite deposits. In assuming so violent a break between the crystalline schists and the next succeeding group we have an indication that he had not yet remarked the universal conformity which subsists between them. Such an unconformable contact has been nowhere observed. In locating the Vermilion iron beds in a horizontal formation, he must have forgotten the fact that they stand in a vertical attitude.*

Notwithstanding the earlier knowledge of the existence of an unconformity at this place, I was myself, perhaps, the first to *identify* the two discordant formations and appreciate the significance of their discordance. My brother says: "This outcrop is supposed to belong to what the Canadian geologists have styled Huronian. It underlies the quartzite and gunflint beds [siliceous schists], apparently unconformably. At least it is another and distinct formation from the slates at Grand Portage" (*Report*, 1880, p. 82). Returning to this spot, in the *Tenth Report* (for 1881, p. 88) he says: "The close proximity of this flint and jasper locality to the next great underlying formation (syenite and slates) makes it one of great interest to the geologist, but so far as scrutinized as yet the true relations of the two formations are not revealed by anything here seen, though there seems to be an unconformability between them." Professor Irving (*Amer. Jour. Sci.*, xxxiv, p. 261) says: "On the north side of the latter [Gunflint] lake, and again to the north of the next lake to the east, called North lake, the unconformable abutment of the Animike series against an older formation of granite and schists is very handsomely shown." By "granite and schists" he means the gneiss and crystalline schists, as is shown by naming the Animike flat-lying schists as the horizon of the Vermilion ores—contrary, however, to the facts. In my announcement which appeared in the *American Journal of Science* for October, 1887, I said: "I have discovered the unconformable superposition of the Animike schists on the slates of the Vermilion series [meaning the Vermilion iron-bearing series now called Kewatin]. The

* Professor Van Hise reaffirms, two years later, the same disproved interpretation (*American Geologist*, Dec., 1889, p. 382). He states that my description of the unconformity was published "several months later." In fact, it appeared in December, while he says Professor Irving's description appeared in November; but my first announcement was in October and Irving's was really in the same number of the *American Journal* (p. 261). Professor Van Hise says: "The article [in the *Geologist*] assumes that the schists referred to above as occurring unconformably below the Animike are the same as the rocks which bear the iron ores in and about Tower and Ely, Minnesota. This is taking as settled the very question at issue." Well, we have a right to take the question as settled. I have myself traced their physical continuity six times, and competent observers on the Minnesota Survey have traced it, all together, not less than twenty-two times. This is no longer a "question at issue."

Animike flint schists, dipping five degrees southward, have been traced by me to within seven feet of the sericitic argillites of the Vermilion series, dipping northeast about 67 degrees."

Other unconformable contacts of the two systems have been observed by the Minnesota Survey. In travelling northward from Ogishke-muncie lake the bowlders of the Ogishke conglomerate gradually disappear, and the groundmass remains as an ordinary, evenly bedded argillite. At the distance of two miles it becomes the porphyrellite schist so characteristic of the region of the arms of Knife lake. Before reaching Knife lake, Epsilson lake is passed. Here, on the north shore, the two systems of schists are seen in contact. There is a general resemblance in external characters, and this is

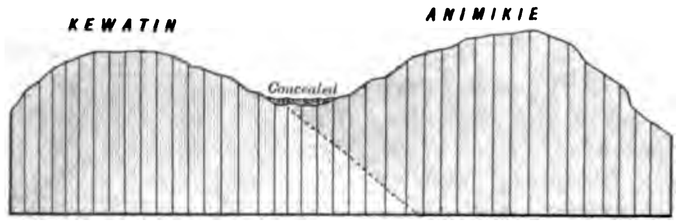

FIGURE 12.—*Showing Unconformity of the Animike and Kewatin Schists on Epsilon Lake.*

emphasized by the fact that the same system of cleavage passes through both; but the real unconformity of the two systems is revealed by the ribboning of the sedimentary bedding, which in the case of the Kewatin schists is vertical and coincident, as usual, with the cleavage, but in the case of the Animike schists is inclined to the cleavage at an angle of 43°.

I do not regard it necessary to cite in detail other examples of unconformity, but some will be found mentioned under the references given below.*

Classification of the Foregoing Rocks.

The enumeration which I have made embraces all the bedded rocks of the vast region northwest of the Great Lakes, up to the so-called "Keweenawan system." This is all there is of northwestern geology up to the horizon named. So far, at least, as the great groups are concerned, the order of succession is simple and plain. We may write them down with confidence as follows, beginning above:

V. The Uncrystalline Schists (Animike, Huronian).
IV. The Semi-Crystalline Schists (Kewatin).
III. The Crystalline Schists (Vermilion).
II. The Gneissoid Rocks } (Laurentian).
I. The Granitoid Rocks }

* *Sixteenth Annual Report*, Minnesota Survey, 1887, pp. 67, 69, 73, 87, 357, 358; *Seventeenth Report*, 1888, pp. 87–'8, 91, 104–'5, 109–'10.

Waiving the question of the taxonomic separability of the granitoid and gneissoid rocks, the fundamental contrasts in condition seem fully to justify the conclusion that a historic break occurs above the gneissoid rocks and another above the crystalline schists. Above the semi-crystalline schists a wide stratigraphic unconformity adds its evidence that we find here also a boundary between two systems. The stratigraphic conformity between the *second* and *third*, and the *third* and *fourth* systems is probably at variance with prevailing opinions, and such a persistent conformity of structure is a fit subject for careful consideration. As I desire in this place simply to present facts, I will only say that I do not imagine the present conformity implies an original parallelism of beds of sedimentation.

The crystalline gradation, from bottom to top of the general series, is simple and remarkable. There are no granites superior to the gneissic zone; there are no gneisses superior to the zone of crystalline schists. Above the zone of crystalline schists no true crystalline schists occur again. The "nascent mica schists" of the *fourth* section retain the palpable evidences of their fragmental origin. We are not met by the anomaly of recurring mica schists at two or three different horizons. As there was only one age of gneisses, so there was only one age of mica schists. So, again, the *fourth* was the age of argillites, felsite schists, and volcanic tuffs, while the *fifth* lies on the hither side of a great continental movement, and is marked, like the preceding ages, by characteristic lithologic conditions—its carbon-freighted argillites, and its floods of silicated waters.

With this observed simplicity of structure, we should entertain great confidence in proposing a final classification were it not necessary to correlate the results with those announced by eastern investigators. Where does the Huronian belong? Where the Taconic? Where the Montalban? Where the Coös group, and the other divisions of New Hampshire? We wish to know, also, how these divisions stand correlated to the Dimetian, the Lewisian, the Arvonian, and the Pebidian of Great Britain, and with the divisions of the Scandinavian scale. To some of these questions I have formulated answers in my own mind; but I do not deem it judicious to extend this memoir. For the same reason, I defer all the more detailed discussion on the petrography of the several systems and on all theoretical questions, such as the origin of the iron ores and the accompanying siliceous and jaspery schists; the conditions of origin of the pyro-clastic rocks; the cause of the foliation in crystalline rocks; the relative ages of the granites and gneisses; and the genesis and history of massive rocks which, by recent opinion, have been by so general consent relegated to the class of eruptives.

DISCUSSION.

Professor C. R. VAN HISE: If I were personally concerned only, I should not occupy time by going into this question at all. I do not feel that my familiarity with northeastern Minnesota would warrant it. Many geologists know that Professor Irving gave a great deal of his time for several years to an investigation of the formations of northeastern Minnesota. During this time he was assisted by Mr. W. N. Merriam and Mr. W. M. Chauvenet, so that the amount of time he has put upon this area, through his representatives and in person, I can safely say far exceeds that of any other single individual; and I may say I think, although I am not so positive as to this, that no other survey has given the region as much time as Professor Irving's.

Now, many of Professor Irving's conclusions are altogether different from Dr. Winchell's. Dr. Winchell began by stating that he intended to give observations only. It seems to me before he had finished he put in many theoretical conclusions. If the diagram drawn on the board (fig. 7) is not a theoretical conclusion, involving as it does a thickness of sediments of over 100,000 feet,* I do not understand in what theory differs from fact. As to the distribution of the rocks outlined by Dr. Winchell, I can bear testimony to its general correctness, with the exceptions that I would not designate certain of the rocks by the names which he gives them and would differ from him as to the character of some of them, whether they are crystalline schists or semi-crystalline clastics.

As to the correlation of these series, Professor Irving held tentatively, not dogmatically, that the Animike series is the equivalent of certain sedimentary rocks in the Vermilion lake section as drawn by Dr. Winchell. As to who first discovered the unconformity below the Animike I will not farther discuss, but will only say that I know positively that Professor Irving recognized it at the time he read his paper before the National Academy, in the spring of 1887.† He recognized it to its fullest extent, and in this matter agreed fully with Dr. Winchell. The chief point of difference is the relation of the Animike rocks and the rocks which bear the iron ores at Vermilion lake. These latter beds are in good part jaspery, and they are associated with rocks which are distinctly semi-crystalline, yet are in places actually conglomerates. The whole area west of the Animike series has been carefully gone

* Report upon a Geological Survey in Minnesota during the season of 1886: Alexander Winchell: 15th Annual Report of the Geological and Natural History Survey of Minnesota, p. 192.
"The situation would then be represented by the following diagram." (The figure is similar to fig. 7.) Then in detail is given the thickness of the various belts of schist. "To this aggregate of schists may be added the observed breadth of the gneiss on the north side, making a total thickness of 106,204 feet."

† Professor Irving and Mr. W. M. Chauvenet examined together the exposures at Gunflint lake and saw evidence of the unconformity referred to in September, 1883. Professor Irving in his field-note book (Sept. 6, 1883) sums up as follows: "The whole appearance [of the] topography, lithology, persistence of rock beds is certainly suggestive of an unconformity here." Says Mr. Chauvenet in his field notes: "There is here evidence of total unconformity."

over by Professor Irving's survey. Thin sections of the rocks collected have been made and examined in detail. The rocks were found to be crystalline schists. Still further to the west is the Vermilion lake series.*

It was Professor Irving's opinion that the fragmental and jaspery rocks bearing ore at Vermilion lake, which are nowhere directly in contact with the Animike rocks, are probably their equivalents. Dr. Winchell admitted that the Animike rocks, besides exhibiting true bedding in certain places, have a cleavage. Professor Irving believed that the section upon the board (fig. 7) represents an intensely squeezed complex series (instead of a simple conformable one 100,000 feet thick), the cleavage of which is secondary, just as described by Dr. Winchell as occurring in the Animike rocks.

The reasons in detail for the above correlation would occupy too much time to present to the Society. In general it was based upon lithological likeness, not only of the masses of the rocks as a whole, but of their individual members. It was based on the unlikeness which the Animike series and the ore-bearing rocks and associated clastics of Vermilion lake have to the crystalline schists below the Animike and north and south of the Vermilion rocks mentioned. It was based upon the comparison of these two groups with the other iron-bearing series of Lake Superior. I can only refer you to Professor Irving's elaborate memoirs for the many facts upon which he rested his conclusion.

Finally, I would say that Professor Irving's ideas as to the complication of the structure of northeastern Minnesota were quite different from those of Dr. Winchell. Dr. Winchell holds that the structure in this region is exceedingly simple. It seems to me that the geological history of the Scottish Highlands is instructive in considering the geology of northeastern Minnesota. It was believed many years ago that the structure of the Highlands was understood, but recent study has shown that the old ideas were largely false; that its real structure is far more complicated than was believed; that it is immensely complicated. The recent study of the Appalachian region is teaching an exactly similar lesson. Professor Irving believed that the crystalline series in northeastern Minnesota is the most complicated in its structure of all of the regions about Lake Superior.

Professor WINCHELL: I trust it will not be assumed by this audience that I undertook to attack Professor Irving's authority on the nature of any kind of rock; least of all have I asserted or insinuated that he was not capable of determining what is mica schist or crystalline schist. That is far aside from anything which I implied.† The statement upon which my friend Van Hise's assumption is grounded is simply my allegation that on

* For the distribution of the formations under discussion as understood by Professor Irving, see 7th Annual Report, U. S. Geol. Survey, 1888, map, p. 418.

† For my estimate of Professor Irving's abilities and services, see *Sixteenth Ann. Rep. Minn. Surv.*, p. 144, note.

the north side of Gunflint lake there are vertical schists which are of the Kewatin age; they are semi-crystalline; they pass into crystalline schists by gradual transition to the northward; and it was my opinion that Professor Irving either failed to observe that unconformity, if he were on the spot and saw for himself, or else failed to notice that the schists upon the immediate shore of the lake, with which the Animike is in contact, were not proper crystalline schists, but were Kewatin or semi-crystalline schists. I have examined sections of these rocks and find they are not all the same thing, but none are "crystalline schists." I will only say further that the Kewatin rocks show sometimes a crystalline structure and at other times a partially crystalline structure; at still other times an earthy condition. You can get hand specimens that are entirely earthy in their structure and nature, and you can get other hand specimens that are quite crystalline, but nothing possessing the appearance of a mica schist. The groundmass is generally one which is distinctly earthy, such as occurs within the limits of the Kewatin.

Professor VAN HISE: Of course we shall differ as to the nature of the schists which underlie the Animike series. I should regard them as far more crystalline than the mica schists north and south of the Kewatin beds, or, more accurately, than the beds bearing iron at Vermilion lake.

Professor WINCHELL: It is a difference of opinion. Time does not suffice to discuss the grounds of our differences. My positions are set forth in my memoir, and it is not necessary to repeat them. I have also, indeed, indicated there the diverse interpretations of Professors Irving and Van Hise. The grounds of my dissent from their interpretations will perhaps be given on another occasion.

My vertical section, thought by Professor Van Hise to be highly theoretical is, I admit, partially so; but if anything more than a mere help to the understanding of the map, it goes but very little beyond a delineation of facts actually observed.

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POST-TERTIARY DEPOSITS OF MANITOBA AND THE ADJOINING TERRITORIES OF NORTHWESTERN CANADA.

BY J. B. TYRRELL, OF THE GEOLOGICAL SURVEY OF CANADA.

(*Read before the Society December* 27, 1889.)

CONTENTS.

THE REGION AND ITS GENERAL GEOLOGICAL FEATURES.

Southwest of the margin of what has long been known as the Archean continental nucleus lies a great drift-covered area, including in it most of the plains and prairies of northwestern Canada. It extends on the international boundary line from the western side of the Lake of the Woods to near the eastern base of the Rocky Mountains, through between sixteen and seventeen degrees of longitude, or a distance of more than 750 miles. Towards the northwest it stretches along the face of the Archean area to beyond the arctic circle in the valley of the Mackenzie river.

Lying on an irregular floor of old gneisses and schists, rocks of Silurian and Devonian age are known to occur over the whole eastern and northeastern portion of this district, while further westward these disappear under others of upper Mesozoic age; and thence westward to the foot of the Rocky

Mountains, Cretaceous or Tertiary beds everywhere underlie the post-Tertiary or recent deposits. The character of most of these beds, which consist of sandstones, marls, and clay-shales, is perfectly well known, but I wish to draw your attention for a moment to the occurrence of conglomerates of Miocene and Pliocene age, the existence of which has been pointed out of late years, since they furnish sources of supply for a large amount of drift which was formerly supposed to have been derived directly from the Rocky Mountains at the same time that the other associated portions of the drift were derived from the Archean and Paleozoic rocks to the east.

The Miocene is at present known as a fresh-water formation of sands, silts, and gravel, or conglomerate, lying on the eroded surface of the Cretaceous and Laramie rocks on the more elevated portions of the Hand and Cypress hills, and on the higher plateaus stretching east from these as far as long. 107° 15′. The pebbles in this conglomerate are all well rounded and waterworn, and consist of a white quartzite similar to that in the Rocky Mountains described by Mr. McConnell as belonging to his "Bow River group," or lower portion of the Cambrian system. This material has been carried eastward by rapid streams during Miocene times, and deposited either in lakes or on the flood-plains of rivers. The gravel has in many places been indurated by the infiltration of a calcareous cement into a hard conglomerate, much harder than the underlying shales aud sandstones, and has preserved the hills that it now covers from degradation by atmospheric and fluviatile agencies to the same extent as the surrounding country, and at the same time has furnished a scale by which to measure the thickness of the rocks washed away since Miocene times.

The Pliocene, here called by Mr. McConnell the "South Saskatchewan group," is also composed of rounded quartzite gravel; but it now occupies the bottoms of valleys or other depressions, and has been derived in part from the pre-existing Miocene deposits, and also in part directly from the quartzite areas of the mountains.

The district under consideration, extending from the boundary between the United States and Canada northward to the North-Saskatchewan river, is largely overlain by a series of heterogeneous deposits which are commonly embraced under the term "drift." This consists of bowlder clay or till, morainic detritus including erratics, drumlins, kames, alluvial sands, clays, and silts, beach-ridges, terraces, etc.

The Glacial Deposits.

Till.—The bowlder clay or till rests irregularly on all the pre-glacial formations down to the fundamental gneisses and schists, and in the Archean area itself fills many protected depressions and recesses. It does not, however, reach the base of the Rocky Mountains, but extends westward to within

forty miles of them, as far as Calgary, on the Canadian Pacific railway, and from there southward to the international boundary it keeps at about the same distance from the mountains. North of Calgary the western edge of the great sheet of till crosses the Red Deer and North-Saskatchewan rivers at approximate elevations of 3,000 feet above the sea, the latter in long. 115° W. Further north it is stated by Dr. Dawson to cross the Peace river in lat. 56° N., long. 119° W. To the south its boundary everywhere lies on the United States side of the Forty-ninth parallel of latitude. North of or near this geodetic line it covers all the country of the plains without regard to elevation, with four exceptions, viz., the upper portions of the Sweet Grass hills above 4,660 feet, the Cypress hills above 4,400 feet, the Hand hills above 3,400 feet, and Rocky Spring plateau above 4,100 feet.

The general character of this great sheet of drift is remarkably uniform throughout, being essentially composed of a gray, more or less sandy clay, massive in character, and holding numerous pebbles and bowlders. It is largely composed of the débris of the Cretaceous and Tertiary rocks that surround or immediately underlie it, consisting probably of the parts of these strata that were rotten from long exposure to the weather during the ages that intervened between the close of the Laramie period and the commencement of that of glaciation. By this latter agency the rotten rock was kneaded up, with the bowlders and pebbles transported from a distance, into a homogeneous mass. That the till is local is clearly seen where the underlying rock has any very marked characteristic by which it can be recognized—as, for instance, the rocks of the Edmonton series of the Laramie, which are associated with numerous beds of lignite. Overlying these rocks, and especially for some distance south of a lignite outcrop, the drift is filled with pieces of lignite sometimes as large as a hen's egg, and the whole mass becomes dark in color from its presence in minute fragments. Another instance is recorded by Dr. Dawson where the drift has a distinctly reddish tint, derived from some neighboring reddish clays of the Laramie formation. The bowlders are, however, largely of eastern origin, being composed of granitoid gneiss, mica-schist, quartzite, diabase-trap, gneiss-conglomerate, and stratified Paleozoic limestone, those of limestone, as well as an occasional one of the other rocks, being usually irregular in shape, with smooth, polished surfaces and sharply marked glacial striæ. The pebbles included in the till throughout the western portion of the district, where they consist largely of white quartzite, the same as that composing the Miocene gravels on the Cypress and Hand hills, are doubtless partly of local origin, having been derived from the gravel on these hills, or from other areas that have been entirely denuded away. Some are also probably derived from the parent beds of Cambrian quartzites in the Rocky Mountains. A few of gneiss are almost everywhere met with, and while the western quartzites

gradually disappear on proceeding eastward those of gneiss become more numerous, and pebbles of Paleozoic limestone also become very common.

In thickness the till varies greatly in different places, ranging down from 500 feet or more to a very thin covering; but, generally speaking, throwing out of account deposits clearly referable to terminal moraines, it becomes slightly thinner from east to west, the outcrops seen along the 3,000-foot contour line above mentioned being as a rule not more than a few feet in thickness.

Throughout the greater portion of the area under consideration the till falls naturally into two major subdivisions, a lower very compact bluish-gray unstratified deposit, and an upper softer and sometimes thickly lamellated clay usually of a light brownish color. These two subdivisions have been chiefly recognized in the extreme western portion of the area, from the international boundary north to the North-Saskatchewan river, where they are often separated by stratified waterlaid deposits, in which, on the Belly river, Dr. Dawson records the occurrence of a bed of lignite eight inches in thickness. The till in this latter locality is also of extraordinary thickness as compared with the average found farther north between the Bow and North-Saskatchewan rivers. Farther east these two subdivisions have not been so generally recognized, probably on account of the great thickness of the whole deposit and the comparative paucity of good sections.

Terminal Moraines.—Intimately associated with the till are a number of irregular ridges of rounded hills severed by deep depressions, in the bottoms of which are often lakelets of clear, sweet water without visible outlets. The rim of the basin of one of these lakes is frequently fifty or sixty feet above the surface of the water, and surrounding knolls in many cases rise to a height of from a hundred to a hundred and fifty feet higher. Sections of these hills show them to be masses of transported material, consisting of unstratified sand, clay, and bowlders, and their sides and summits are almost always thickly strewn with large northern or eastern erratics.

As to the mode of formation of these hilly tracts, there is now little room for doubt that they were the terminal moraines of one or more extensive glaciers that moved outwards from the central Archean nucleus, planing off the higher points of the surface and shoving before them the accumulated mass of mixed material. Much of this fell back under the moving ice in the depressions of the preglacial surface, while the rest, consisting chiefly of the coarser material, continued at the ice-foot, and was left as an irregular ridge on the final retreat of the glacier. Very few of these morainic belts have as yet been definitely located, but the following may be mentioned as some that have been examined in late years and whose character is pretty certainly known.

On the western margin of the Winnipeg basin, a rugged morainic ridge

runs along the face of the northern continuation of the Pembina escarpment, with a mean elevation of 1,600 feet. In the great depression drained by the Valley river its width is from a quarter to half a mile. It is composed chiefly of sand, but it also contains very many large bowlders of dark-gray and reddish gneiss, mingled with others of Paleozoic limestone.

Proceeding a little further to the west, the whole surface of Duck mountain is found to consist of irregular ridges and knolls of gneissic débris rising in some parts to a height of 2,000 feet above Lake Winnipeg, or 2,700 feet above the sea. This rugged tract extends southward over the summit of the Riding mountain, and it is not improbable that the Brandon hills (which have been described to me as having somewhat similar characters to those already mentioned) may be a southern continuation of the same extensive ridge.

Proceeding still farther westward along the Forty-ninth parallel of north latitude to the westward margin of what has been known as the second prairie steppe, a wide belt of rounded morainic hills is reached, lying on a sloping preglacial surface rising gradually from east to west. This hilly country, which has been known since the time of the early voyageurs as the Missouri Coteau, was well described by Dr. Dawson in his report on the geology and resources of the Forty-ninth parallel. It has also been identified by Professor T. C. Chamberlin as the continuation of the great terminal moraine of the second glacial period, which has been traced by himself and others from Dakota eastward to the Atlantic Ocean. From the northern boundaries of Dakota it has been traced by Mr. McConnell northwestward in Canada for two hundred miles to a point on the South-Saskatchewan river, twenty-five mile above the elbow, crossing the line of the Canadian Pacific railway in the vicinity of Secretan station. North of this point its course is not at present known, and it must be borne in mind that north of the Fifty-first parallel of north latitude the plains lose to a great extent their eastern slope, the summits of the Duck mountain, in long. 101° W., being equal in height to the general surface of the country due west of them in long. 113° W., or more than five hundred miles distant. Since, then, the slope on which the moraine constituting the Missouri Coteau was deposited becomes very indefinite or dies out a little north of the South-Saskatchewan river, it is not improbable that the course of the moraine itself is much changed, so that it may curve around and join others that are now known to the east or west of it. It is, however, more probable that it is here an interlobate moraine, and that as a definite entity it does not extend much further north than its present known limit.

West of the Coteau the till is of essentially the same character as that to the east of it, and numerous detached ridges of "rolling hills" or terminal moraines are known to occur. In describing the vicinity of the Cypress hills Mr. R. S. McConnell classes with the Coteau, as being "covered with

steep-sided drift-built hills," the "ridge extending northwest from Pinto-horse butte" (near the head of the middle branch of Old Wives creek and in approximate lat. 49° 45′ N., long. 107° 45′ W.) in a general direction parallel to the Coteau and about fifty miles southwest from it, and the "spur south of the west end of the Cypress hills" a hundred miles still farther west.

West of this ridge and south of lat. 51° N. no terminal moraines have been recognized, except such as have been formed by glaciers flowing from the valleys in the mountains, these being characterized by the angularity of the included pieces of rock and the absence of eastern erratics. North of lat. 51° N. there are a number of ridges of distinctly morainic character. One of the most typical of these surrounds the southern and eastern sides of the Hand hills. These latter hills form a high table-land rising twelve hundred feet above the surrounding plains, and are surmounted by two hundred and seventy feet of sands, silts, and gravel of Miocene age. Towards the northwest, west, and southwest they rise in an abrupt escarpment five hundred feet to their summit; towards the east and southeast they decline gradually and regularly for a short distance, and then the slope is covered with a ridge of rounded knob-like hills separated by deep kettle holes, in the bottoms of which often nestle small isolated lakes. Their summits are thickly overstrewn with bowlders.

From fifty to sixty miles further north, near the southerly bend of the Red Deer river, another similar ridge is met with, the knolls rising in many places to more than two hundred feet above the bottoms of the depressions.

Turning directly eastward a rough, irregular tract, known as the Neutral hills, is seen, the higher points of which are thickly covered with gneissic and limestone erratics, lying on a base of unmodified morainic material. The hills themselves lie on an elevated plateau of Cretaceous shale, which has been very irregularly eroded, so that it is often difficult to say without sections whether an individual hill is a product of denudation or is one of the irregularities of the moraine.

North of the Battle river the Blackfoot hills form another area of deep, unconnected depressions and high, rounded knolls, sprinkled over with bowlders of eastern gneiss.

Other morainic belts doubtless occur in this area south of the North-Saskatchewan river, but as yet they have not been traced out. Enough has been done, however, to show the former existence of a great glacier, or "mer de glace," which spread over the plains from a source or sources of supply on or north of the Archean rocks to the east, and which flowed in a southerly and southwesterly direction almost to the foot of the Rocky Mountains, from whose valleys numerous small glaciers flowed eastward to join the mighty advancing ice-sheet, leaving intervening areas along the foot of the mountains, and roughly west of the 3,000-foot contour line, unglaciated.

Absence of Terminal Moraines near the Rocky Mountains.—The absence of a terminal moraine at the extreme western limit of the till, near the foot of the mountains, is a fact worthy of notice, especially in view of the fact that the till of both the earlier and later glacial periods is found to extend approximately the same distance westward, and that there is a narrow belt from thirty to one hundred miles in width that would appear never to have been covered by the ice-sheet.

The most efficient reason that suggests itself to me to account for this state of affairs is that the glacier terminated in one or more lakes, hemmed in between the continental glacier and the mountains and cut off towards the north and south by lateral glaciers flowing eastward in such valleys as those of the Bow and North-Saskatchewan rivers. The morainic accumulation would in that case be carried off either by icebergs or waves and currents and spread out some distance beyond the limit of the till. This would account for the presence of eastern erratics along the very foot of the mountains, and may also account for the high terraces on the sides of such valleys as that of the North Kootanie river. This condition could not, however, have lasted for any great length of time, as no considerable amount of stratified deposits are found in this unglaciated area.

Western Pebbles.—The presence of western pebbles in the drift far out on the plains was for a long time an almost insuperable barrier to the general acceptance of the belief in its essentially eastern origin; but the discovery of large areas of Miocene conglomerates, holding these same pebbles, as far east as long. 107° W., has almost entirely overcome this objection in furnishing new centres of distribution from which these pebbles have been carried. Still it is not improbable that some of the drift in the extreme western part of the drift-covered country is derived from the mountains, having been carried down by the local glaciers mentioned above.

Direction of Ice Flow.—In speaking of the general direction of flow of the western portion of the great continental mer de glace it has been customary to regard it as having advanced southwestward from the Archean area—and certainly this was the direction of glacial motion when the ice first reached the Winnipeg basin,—but recent investigations have shown that in two cases, at all events, this direction was not sustained, viz., in the great Winnipeg valley, and in the valley of the upper Assiniboine, west of the Duck and Riding mountains. In both these cases the direction of flow was southward or southeastward in the direction of the trend of the valleys, and parallel to the main axis of the Rocky Mountains. This direction was in all probability sustained by the glacier all the way across the Canadian plains, and we have thus one reason for its great extent, as the ice was moving from a wide area of distribution to a much narrower area of dissipation, and there would be a constant tendency to make up for the loss from the surface by a crowding in from the sides.

Deposits of Isolated Glaciers.—After the final retreat of the general continental glacier, relatively small névés remained on the tops of some of the higher elevations that had previously been overridden, and small glaciers flowed outwards from them down valleys of various depths. The Duck mountain shows many evidences of having passed this intermediate stage of local glaciation. It is a high table-land, the summit of which rises 2,700 feet above the sea, or 2,000 feet above Lake Winnipeg, and consists entirely of Cretaceous clays overlain by a great thickness of unstratified till and transported bowlders, most of the latter being Archean gneisses and schists. From the summit of the mountains several large valleys carry the superfluous drainage outwards to the various surrounding waterways. The stratified deposits in these valleys are in many cases overlain by unstratified till. The valleys are also blocked by small local moraines, behind which in some cases the valleys are terraced as high as the tops of the moraines, while in others the rivers that formerly occupied them have been permanently diverted into other channels.

Thus we would appear to have in this area three distinct bowlder clays, two formed by the continental glacier moving southward, and the third or upper formed by local glaciers existing at the same time that the great post-glacial lakes filled all the adjacent depressions.

Drumlins.—Over the great portion of the plains drumlins have not been recognized, possibly in part because in the press of other work they have not been looked for sufficiently; but in the northern portion of Lake Winnipegosis many excellent examples are to be seen. They here form groups of narrow, very much elongated elevations in the till, rising in islands a few feet above the surface of the lake, and are generally thickly covered with transported bowlders of gneiss and limestone. A very casual glance at these groups of islands will serve to show that they are structurally different from neighboring ones underlain by rock and on which the bowlders have been shoved by the ice. There is no sign of any rock in place and the stones are not all of constant lithological character, as is generally the case where the rock is close to the surface, but they are true transported bowlders, differing as widely from each other as crystalline gneiss and coralline limestone. The islands are also formed with their long axes parallel to the direction of the glacial striæ in the vicinity.

The Aqueous Deposits.

Interglacial Deposits.—As has been already shown, the evidences of a recurrence of glacial conditions and the intervening temperate era near the northwestern limit of the glaciated area leave no room for doubt that the glacier retired for a considerable time from the greater part of the western prairie region; and perhaps during this interglacial period conditions may

have been much as they are now, for near the northern end of the Duck mountains there is a deposit of stratified silt underlying a great thickness of unstratified till, and probably of inter-glacial age, holding numerous fresh-water shells, with fragments of plants and fish remains essentially the same as those living in Lake Manitoba and the surrounding lakes to-day.

Kames.—Very few kames have up to the present been definitely located in the Canadian northwest, and none that would appear to have been connected with any but the later stage of glaciation, viz., that of isolated local glacial centres. The most important of these stretch as straight ridges down the middles of deep valleys on the east side of the Duck mountain. The two most important ones recognized were covered by several feet of pebbly unstratified till, the same as that composing the surrounding hills. In some cases what have been taken for moraines may possibly be kames, but it is difficult in all cases to distinguish them in the absence of sections.

Lacustral Beds.—Resting on the bowlder clay throughout very extensive tracts in Manitoba and the North West territories are stratified sands, silts, and clays that have been deposited in the bottoms of post-glacial or recent lakes. The delineation of these lake basins is a work of the greatest economic importance, as it is evident from what we at present know—that many of the most fertile tracts in the west are underlain by rich alluvial clays deposited in the bottoms of sheets of water of greater or less extent, which have now disappeared.

The number and extent of most of these old lakes has not as yet been determined, but the positions of a few may be here generally indicated.

The country drained by the upper waters of the Bow, Red Deer, and North-Saskatchewan rivers, having at present a mean elevation of between two and three thousand feet, was largely submerged, fine clays and silts overlying the till being here very generally met with, though no shore lines have been recognized. A marked peculiarity of these deposits is the utter absence in them of any shells or other fossils that would indicate the existence of life in the lakes in which they were deposited.

Another extensive stratified deposit skirts the eastern margin of the Missouri Coteau.

The depression lying west of the Duck mountain, which is now drained southward by the Assiniboine river, was also, at the close of the glacial period, the basin of a large lake which first drained eastward through the valley of Short creek and Valley river, between the Duck and Riding mountains, and afterwards, when this valley was blocked by a local glacier from the Duck mountain (the terminal moraine of which still stretches across its western end), cut out the present valley of the Assiniboine. Southward, this lake extended down to lat. 51° N. Its northern and western boundaries have not yet been determined; but standing on the morainic

ridge that forms the western side of the Duck mountain, and which was also the eastern shore of the lake, a wide, level, alluvial plain or lake bottom may be seen stretching westward to the limits of vision.

But by far the largest and most important of these ancient post-glacial lakes is that named Lake Agassiz by Mr. Warren Upham, and which once occupied the Winnipeg basin and the valley of Red river. In its bed was deposited the rich alluvial clay that is now enabling Manitoba to take its place as one of the foremost wheat-producing areas in the world.

Ancient Beaches.—I shall not now discuss the altitude, length, and depth of these lakes; but a few words may be said of the beaches that at various times formed the shore lines for the gradually receding waters.

The existence of the old shores of Lake Agassiz was clearly pointed out by Professor H. Y. Hind in 1859, but their relative heights were not at all understood by him. Of late years Mr. Warren Upham has carefully studied these beaches from Lake Traverse, at the south end of the Red river valley, to a short distance north of the 50th parallel of north latitude. In the wooded district further north, and one hundred and fifty miles north-northwest from where the old lake beaches cross the international boundary at the foot of the Pembina escarpment, several gravel ridges were located by the writer on the northern face of the Riding mountain, close to the banks of Ochre river, a small stream flowing into Lake Dauphin. The heights of these ridges are respectively 1,215, 1,115, and 1,025 feet above sea level. From Ochre river they were followed for eighteen miles in a northwesterly direction, at the end of which distance the highest one runs along the summit of a steep escarpment one hundred feet in height, while the one below it is continuous with the line of the base of the cliff. The face of the cliff is now overgrown with trees, but a gulley that cuts back into it shows it to be composed of the white limestones and chalk-marls of the Niobrara subdivision of the Cretaceous.

The sequence of events is here very beautifully shown: For a considerable time the lake stood at the level of the highest of these beaches, and the land sloped gradually beneath the surface of the water. The lake then fell more or less rapidly a hundred feet to the next lower shore line, and must have stood at this level for a long time, sufficiently long at all events to allow the waves to cut a cliff of limestone one hundred feet in height from what was before a gradually declining surface.

From this chalk cliff, which formerly must have stood out boldly as a conspicuous landmark on the shore of Lake Agassiz, coast ridges were again followed and crossed at intervals in travelling northward to Valley river. This stream flows in a wide depression separating Duck from Riding mountains. The highest beach ridge seen on its banks has an elevation of 1,280 feet above the sea, but above this is an extensive sandy plain covered with

stunted grass and dotted with a few scrubby oak trees. This plain is a delta deposit of a river that flowed into Lake Agassiz when this lake was at its highest stage; and on the sides of the channel which the present river has since cut through the plains a number of very interesting and instructive sections can be seen, including both the superficial deposits and the underlying Cretaceous.

Beyond the Valley river the ridges continue in a direction 15° west of north for sixty miles, to the northeast angle of the Duck mountain, when they turn abruptly westward into the valley of Swan river. Crossing this valley they are well marked on the eastern face of the Porcupine mountains, north of which they turn westward for a long distance into the vallay of Red Deer river, ending in a wide, flat, sandy delta plain.

Whether they extend along the face of the Pasquia mountain has not yet been determined; but the Pas ridge on the Saskatchewan river would appear, from descriptions we have of it, to be one of these ancient beach ridges, though its elevation is not nearly so great as most of the well defined ridges along the face of the Duck and Porcupine mountains.

These beaches as a rule are in the form of slightly rounded ridges from fifty to two hundred feet high, raised from three to twenty-five feet above the surrounding country. They are composed of sand and small water-worn pebbles, a few of which are granitic or quartzitic, while a great majority are of the white Paleozoic limestone at present outcropping around the adjoining lakes. The gravel must, however, have been derived entirely from the till that had previously been carried by the glacier from the bedded rock at a distance, for there is now no known outcrop of these limestones with a greater elevation than about nine hundred and thirty feet, or more than five hundred feet below the summit of the highest of the gravel ridges. Cliffs of till that might furnish sources of supply for the pebbles are also often separated by very long intervals; so that it is probable that most of the gravel was brought down by rapid streams flowing from the adjoining mountains, and was distributed by currents along the shore.

The beaches would appear essentially to have been formed by waves and currents, as there are very few signs of ice action such as are seen around the shores of Lakes Winnipegosis and Manitoba to-day.

Where most conspicuously developed the beaches are covered, as a rule, with only a meagre growth of short grass, which in some of the more northern parts is varied with a few stunted trees of Banksian pine. They thus often form beautiful dry roads through country that would otherwise be an impenetrable forest.

So far as the eye can detect, the line of the crest of the ridge is quite horizontal, but careful measurements show it to rise gradually and regularly towards the north, just as the crests do in Minnesota and Dakota. At

the boundary line the ridges range in altitude from 995 to 1,230 feet above the sea,* while on the eastern face of the Duck and Riding mountains they were found to ascend as high as 1,460 feet above the sea, showing a rise in the upper boundary beach, supposing it to continue this far north, of about one foot to the mile from the point of crossing latitude 40° north to the Duck river, where the highest beach was seen. If the highest beach at the boundary does not extend so far north, the rise per mile will be somewhat greater.

Very few fossils that can be clearly identified have been found in these gravel ridges; but on Valley river in lat. 51° 13′ N., long. 100° 20′ W., at a distance of two feet below the surface, some roughly chipped fragments of quartzite have been discovered, lying horizontally among the disk-shaped waterworn pebbles, along with a small bone of a mammal. Precisely similar fragments are now to be found on the shores of lakes Winnipegosis and Manitoba in association with well-formed arrow-points, and the traditions of the Indians go back to the time when they were formed and used by their forefathers. As the gravel had been laid down by water action and was quite undisturbed, they clearly indicate the existence of man at the time when this lake beach was being thrown up, and it is probable that here, near the mouth of the former representative of Valley river, was one of his favorite haunts. The summit of the beach in which these "chipped flints" were found is 425 feet above lake Winnipeg or 1,135 feet above the sea.

The positions of the northern and eastern shores of Lake Agassiz have not yet been determined; but from what we know at present we can safely say that there is no land in that direction sufficiently high to form a shore line with an elevation of 1,400 or more feet, and there has been no evidence forthcoming to show that there has been any other disturbance of the country since the lake was at its highest level than the slow uplift towards the north shown by the gradual rise of the ridges in that direction. The theory has been suggested that the face of the retreating continental glacier held back the water on these two sides. It is not improbable that as the glacier retired from the face of the country, which was sloping towards it, a lake would be formed at its foot. If this be the true explanation of the cause of the formation of Lake Agassiz, it discharged its surplus water through the valley of Lake Traverse until the glacier had retired far enough or had decreased sufficiently in size to allow of a discharge for the lake over or around it. The position of this river has not been and may possibly never be determined, as all traces of it may have since been swept away.

Much has yet to be learned of the history of all of these post-glacial lake beaches, but a long array of interesting facts is now being gathered together, which it is hoped will before long solve some of the mysteries of Quaternary dynamical geology.

* The Upper Beaches and Deltas of the Glacial Lake Agassiz, by Warren Upham: Bull. 39 U. S. Geol. Survey, 1887, p. 17.

DISCUSSION.

Mr. J. E. Mills: I should like to mention, in connection with this paper, General Warren's account of the cañon of the Mississippi. He traced the Mississippi cañon up to that of the Red river, and thence on to Lake Winnipeg. He inferred from what he saw that the cañon when first formed was higher than now, and that the waters of the Winnipeg flowed at that elevation southward. He inferred, also, that the cañon was formed by a river much larger than the present Mississippi. General Warren announced this about 1869. I had the pleasure of doing a part of the geological work of his survey. If I understand Professor Chamberlin rightly, the cañon was excavated between the two glaciations. In that intermediate period the drainage of Lake Winnipeg was southward through the Mississippi valley, and if General Warren's account is correct, the country north of Lake Winnipeg must have been drained southward. Professor Chamberlin shows that at this very time the country of the lower Mississippi was at base level—was very low. There certainly was an elevation, therefore, that caused the erosion of the Mississippi cañon about that time. This seems to confirm and strengthen General Warren's deduction that there was an elevation, and an elevation increasing northward. I should like to have Mr. Tyrrell state what bearing his observations have upon this deduction of General Warren's.

Mr. Tyrrell: The problem of the direction of the preglacial drainage of the Lake Winnipeg basin is a long and complex one. I can merely say here that much of the evidence at present in hand goes to show that it was drained by a river flowing with a more or less northerly course. I know of no evidence found in Canadian territory that will serve to indicate the direction of drainage in the interval between the first and second glacial periods. In the Winnipeg basin the tracks of the older glacier have been obliterated or greatly obscured by the severe erosion of the later glacier. Generally speaking, one must look farther south or nearer the ancient ice-front for the clearest evidence of the earlier glaciation, though it is quite probable that interglacial beds exist in Manitoba. In the postglacial period the Winnipeg basin was first drained southward through the valley of Lake Traverse and down the Minnesota river, and afterwards in a northerly or northeasterly direction, as at present.

On this latter subject, however, I beg to refer to President Chamberlin, who has given the matter a large amount of attention.

President T. C. Chamberlin: The cutting of the trench from the outlet of Lake Agassiz down to the Mississippi was a work which followed the main glaciation of the second period, and was not a part of the great trenching of the Mississippi to which I referred in my paper.

I think we should be scarcely less than stolid—we of the United States—if we did not strike hands with our brethren across the border over a paper which brings into such beautiful consonance the phenomena on the two sides of the international boundary. This paper sets forth the phenomena of the great plains on the north of the boundary in precisely the same terms and under the same interpretations that we have been accustomed to use on our side of the line.

That which strikes me most, beyond this gratifying consonance, is the remarkable extension of our knowledge which this paper and the two preceding papers relating to the northwestern part of our continent* give us with respect to the delimitation of the ice sheets. The boundary line in the western portion of the plains of the Dominion has been represented as extending nearly parallel with the foot of the Rocky Mountains down to our boundary. It continues essentially parallel to the Rocky Mountains southward in our territory to the vicinity of the Sun river, then curves east and, crossing the Missouri river, swings northward on the north flank of the Lightwood mountains, and thence northeast until it strikes the Missouri again at the mouth of the Judith river; then, swinging back, it courses east to the vicinity of Bismarck, where it once more turns south and keeps near the course of the Missouri river until it strikes the Mississippi. So the delimitation in the western portion of the Dominion is brought into perfect harmony with that reported by the United States Geological Survey. Taking this in connection with the facts given in the preceding paper, it is scarcely a jump of interpretation to project this line along the foothills of the Rocky Mountains north to the border observed in the Mackenzie basin, and thence on to the delta of the Mackenzie, which practically carries the delimitation to the Arctic sea.

The limitation of this border to a line off the eastern base of the Rocky Mountains is a remarkable fact when we consider the low condition of the plains east of them; and the further fact that the glaciers of the Rocky Mountains had only a moderate extension is very remarkable. We must bear in mind that these mountains are very high and very broad, and that there sweep over them breezes bearing an unusual load of moisture, much more than the winds that sweep over the Scandinavian mountains on the other side of the Atlantic. Yet, nothwithstanding all these highly favorable conditions, they were not the source of any extensive glaciation, but, on the contrary, the great glaciation came from the far lower heights of the eastern part of the continent and spread across the vast stretches of the great plains. This, it seems to me, is a fact of profound consequence, and its colossal character ought not to be overlooked.

* By I. C. Russell and R. G. McConnell; the former printed among the memoirs (pp. 99–162), and the latter in the proceedings, in this volume.

Professor N. S. SHALER: I should like to ask whether this evidence, brought to us from north of the boundary to the United States, does not go still further and show that the last glacial period in North America was in some way connected with the conditions of the northern Atlantic ocean? The evidence now goes to show that it is a symptom of climatic conditions on the north Atlantic; and therefore it is our task to interpret the phenomena by the facts that have taken place in that ocean basin. It seems to me it is by the increased precipitation of the vapors taken from the warm waters to the sea that we may most easily explain the conditions of the last ice period.

I have recently had an opportunity to study the surface geology of Florida, and it seems to me probable that in the glacial times, or about the time of the last glacial period, the Gulf Stream flowed freely over the surface of Florida up to the northern portion of the lake district. The appearance of Florida seems to indicate that the tide at this time extended from the northern part of the lake district to the Cuban shore. It seems to me likely that we may attribute a glaciation in the eastern part of Europe and Asia and the northern part of North America to the changes in the flow of this stream dependent on modifications of the coast line topography of the region of the Caribbean and the Gulf of Mexico.

Mr. W J MCGEE: I have recently ascertained that during early Pleistocene time—during the first of the two great ice invasions which all geologists are recognizing—not only was all of Florida submerged, but two-thirds of Georgia and the greater part of South Carolina. The submergence in South Carolina reached 550 or 600 feet, and over the low-lying plains there lies a mantle of coast sands deposited during the period of submergence. These coast sands have been found continuous with the Columbia formation of the northern part of the Atlantic slope.

Dr. J. W. SPENCER: With the conclusions of Professor Shaler and Mr. McGee I concur. I have seen apparent Pleistocene deposits in Alabama at about 675 feet above the sea. Over plains and hills of the great Northwest of Canada, also, I have seen bowlders scattered upon the surface of both Paleozoic and Cretaceous rocks. In many cases these are of secondary origin, having been left upon the washing away of the finer materials from the older bowlder clay. Few or none of those erratics which I have seen have been primarily derived from their original sources, although many have been again transported by the floating ice of now shrunken or extinct lakes or seas.

From the occurrence of elevated beaches described by Mr. Tyrrell and others in the North West territories, and from the remains of still higher beaches about the Great Lakes, I am inclined to generalize and bring down the whole continent to make the beaches mark sea-level in the last stages of the Pleistocene period after the episode of the last till.

Mr. TYRRELL: I may say a word with regard to the bowlders referred to by Professor Spencer as scattered over the surface in the Northwest. It is being recognized by a number of explorers that there is probably some little difference in origin between the bowlders lying on the surface and those in the underlying bowlder clay. In many cases it is impossible that the bowlders could have been derived by denudation from the bowlder clay beneath; and I am rather inclined to suggest the explanation that those bowlders were transported in the mass of the glacier itself instead of having been beneath it, as was the till, and that as the glacier melted and retired they were dropped on the surface. I think that this explanation will fairly account for the presence of most of the solitary local bowlders on the surface of the plains, where they cannot be accounted for by erosion.

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SANDSTONE DIKES.

BY J. S. DILLER.

(*Read before the Society December* 28, 1890.)

CONTENTS.

INTRODUCTION.

Several years ago, while studying the Cretaceous shales upon the northwestern border of Sacramento valley in California, I observed in a stream bed a number of large fragments of sandstone. They were carefully examined

for fossils, in the belief that the rock from which they were derived was regularly interstratified with the Cretaceous shales. Near by I discovered an excellent exposure of a vertical dike cutting through the bank of tilted shales from top to bottom, in plain view for a distance of 60 feet. When I reached the dike and found it to be composed of sandstone, the same I had examined for fossils, my interest was thoroughly aroused. A sandstone dike seemed a paradox. Further search in that region brought other dikes of the same nature to light, but the puzzle was not investigated until last summer, when, with the aid of Mr. J. Stanley-Brown, a geologic map of the district was prepared.

Distribution of the Sandstone Dikes in Northern California.

General Relations.—The position of the region containing the dikes is indicated upon the accompanying map, figure 1, by the small rectangular area bounded by heavy lines near the center of the map. The heavy line within the rectangle shows the general direction of the dikes.

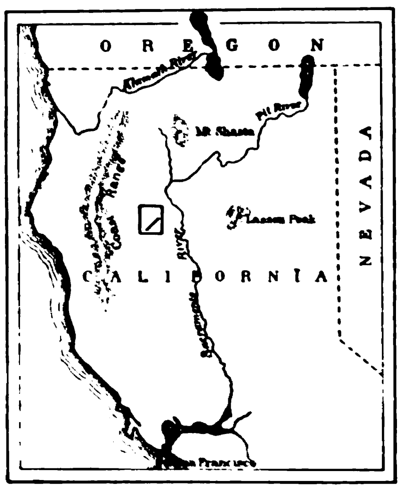

Figure 1.—*General Map of Northern California.*

The rectangular area near the center shows the position of the sandstone dike district, which is represented upon a larger scale in figure 2.

West of Red Bluff, California, there is a wide and comparatively low pass through a part of the Coast Range between the peaks of Yallo Bally and Bully Choop to Hay fork of Trinity river. The eastern slope of the pass is drained by the converging tributaries of Cottonwood creek, which unite to form the main stream twenty miles west of the Sacramento.

Across a base level of erosion, formed by the planing off of the top of the Cretaceous shales and sandstones, these streams have cut valleys considerably

below the general level, and exposed numerous sandstone dikes. The northernmost exposures of these dikes are along the North fork of Cottonwood creek; thence they continue in a belt southwestwardly across Crow and Squaw creeks, Roaring river, Middle fork, Dry creek, and Salt creek, nearly to Cold fork, occurring in an elliptical area about eighteen miles long and six miles in average width.

The distribution of these dikes is illustrated upon the accompanying map, figure 2. Only those dikes which are 18 inches or more in thickness are

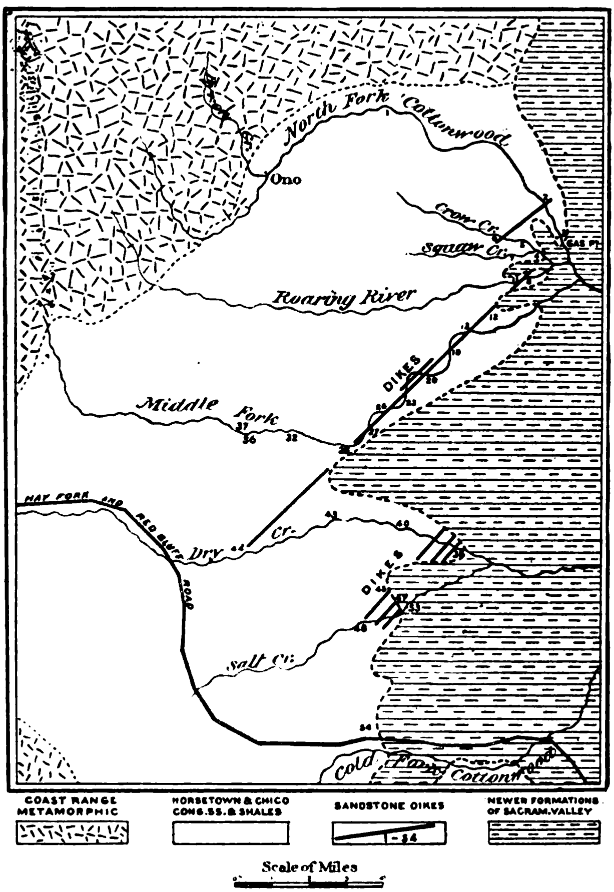

FIGURE 2.—*Map of the Sandstone Dike District.*

Only those dikes which are 18 inches or more in thickness are represented. The serial numbers, some of which are omitted, designate localities.

represented. For convenience of reference, the localities of dike exposures are numbered; but on account of the small scale of the map some of the

numbers are omitted. It is probable also that there are a number of undiscovered dikes not represented upon the map. The shales in the banks of the streams must be well exposed in cliffs or the dikes they contain will not outcrop. Along a portion of Squaw creek and near the mouth of Middle fork the banks are so low and covered with soil that dikes, even if they do occur there, would not be exposed.

Dikes on the North Fork.—At 1 on the map, three-quarters of a mile below the mouth of Eagle creek, there is an 18-inch dike of micaceous sandstone well exposed in a portion of the creek bed and part way up the northern bank, but upon the southern slope it was not found. The strike of the dike is N. 45° E.,* and the dip 75° to the N. W., and of the adjacent sandstones and shales of the fossiliferous Horsetown beds the strike is about N. 10° W., and the dip 15° to the N. E.

The dike is so inconspicuous as a topographic feature that it might be easily passed by without being discovered, and yet it is sufficiently well exposed to show its relations clearly. It is the northwesternmost dike of the region, being four and three-quarters miles from the nearest dike further down the creek.

One mile above Gas Point, at 2 on the map, there is a group of six small dikes, the most important of which are represented in plate 6, figure 3. The largest vein is four inches thick and traversed by many cross-fractures which give it a columnar aspect. The three veins combine as they ascend the bank, but soon run out and fail to reach its summit. The small vein upon the right diminishes downwards to a mere film, sometimes disappearing altogether, although the joint fissure which it occupies is well developed. Traces of joints may be seen in the shale to the right of the dikes, and some of them contain thin films of fine micaceous sand exactly like that of the larger dikes. The plane of stratification in the shales is distinctly marked by variation in the sediment, as well as by lines of calcareous nodules, and it appears that there has been no faulting along the dikes. The boundaries of the larger dikes are generally well defined, as are also those of many small ones, but near the tapering edges they are frequently difficult to recognize.

A short distance to the left of the above vein there is another 2-inch vein which suddenly disappear upwards; and near by is the 4-inch vein represented in plate 7, figure 2, traversing a bluff 30 feet in height. A few feet to the right of the dike and parallel with it is a well-developed joint. The dikes are generally vertical, but this one inclines 65° to the N. W., which is the greatest divergence from the vertical position observed. The general inclination of the shale at this point is about 15° to the southestward.

Opposite Gas Point, at 3 on the map, there is a 14-inch dike which is

* All directions recorded in this paper are magnetic. The variation for that region is between 17° and 18° to the eastward.

FIG. 1.—SANDSTONE DIKES ON ROARING RIVER. 1 FOOT AND 6 INCHES THICK.

FIG. 2.—GREAT SANDSTONE DIKE ON ROARING RIVER. 5 FEET THICK.

FIG. 3.—GROUP OF SANDSTONE DIKES ON NORTH FORK. THE LARGEST 4 INCHES THICK.

FIG. 4.—LATERAL VIEW OF SANDSTONE [illegible] ON DRY CREEK.

illustrated in figure 3. Its strike is N. 55° E., and its dip 82° N. W., penetrating the Cretaceous shales without faulting or indurating them in the least. This exposure is of special importance in showing that the dike does not penetrate the tuff and beds which lie beneath it upon the upturned shales.

Dikes on Crow Creek.—Half a mille above the mouth of Squaw creek, at 4 on the map, is a 4-inch dike exhibiting good joints. Its strike is N. 71° E. At 5, half a mile further up the stream, there is a well defined vertical dike 1 foot in width ; strike N. 63° E. Near by is one 7 inches thick. Its strike is N. 56° E., and with increased width (1 foot) it continues up stream for several hundred yards.

About 1½ miles above the mouth of Squaw creek, at 6, is a group of prominent dikes approaching the valley from the northeast. The first is about 2 feet in diameter, and the other three are about half as large. One of these crossing the little valley enlarges and becomes 4 feet thick, and forms a prominent, wall-like bluff twenty feet high, shown in plate 7, figure 1.

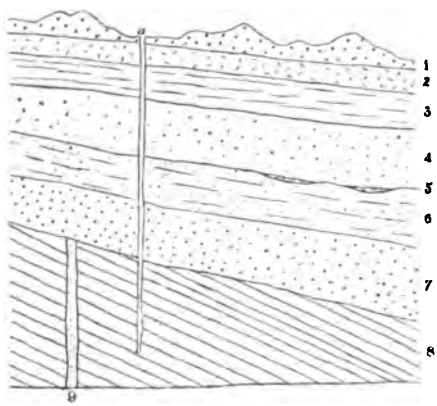

FIGURE 3.—*Section exposed on the North Fork of Cottonwood Creek at Gas Point.*

A 14-inch sandstone dike (9) penetrates the Cretaceous shales (8), which are overlain unconformably by the late formations (1-7) of the Sacramento valley. *a*=Sluice-box; 1=Auriferous gravels of Red Bluff formation ; 2=Tuscan tuff, 3 feet; 3=Clay, 4 feet ; 4=Irregular, fine yellowish gravel, 8 feet; 5=Tuff (?) ; 6=Irregular, reddish clay and sand, 12 feet; 7=Ferruginous gravel, sometimes cemented, 12 feet; 8=Cretaceous Shales (Chico); 9=Sandstone dike.

The transverse cracks in this dike are parallel to the stratification in the shale at the right. They so divide the dike into blocks that it resembles courses of masonry. This resemblance has led many people of the district to regard the dikes as ancient walls, perhaps of some prehistoric people. This is the largest exposure of the kind seen in the country, and is well known for the excellent shade it affords from the hot afternoon sun.

Near by is another dike, 5 feet in thickness. Its strike is N. 40° E., and it can be traced in that direction across the little vale to the hill a quarter of a mile away. A short distance northwest of these dikes the valley of

Crow creek narrows, and numerous fossils have been found in the conglomerate which forms the hills. The conglomerate is apparently the one which crosses the North fork just below the mouth of Hulen creek and belongs in the Chico series. All of the dikes, excepting the one already noted on the North fork three-quarters of a mile below the mouth of Eagle creek, traverse strata which apparently overlie the Chico conglomerate.

Dike on Squaw Creek.—At 7, on Squaw creek, there is a 14-inch vertical dike which strikes N. 53° E. The direction of Squaw creek and its gentle slopes are such as to yield poor exposures of the underlying rocks, and if other dikes are there they are not easily discovered.

Dikes on Roaring River.—The dikes already noted on the North fork and on Crow and Squaw creeks are not clearly related to one another—*i. e.*, the same dikes cannot be recognized with absolute certainty in two valleys. In a general way it appears that the group of small dikes on the North fork, one mile above Gas Point, represents the group of large dikes at 6 on Crow creek, and they have been so drawn upon the map; but their connection has not been traced, nor can it be easily on account of the soil on the broad divide between.

On Roaring river, however, begins a series of dikes which can be traced for a considerable distance. One of the number, which will be called the *Great Dike*, can be recognized for about 9½ miles. It is first seen at 8, three-quarters of a mile above the mouth of Roaring river, on the left bank of the stream, with a thickness of 20 inches. Section 2539 is from this dike. Its position was vertical and parallel to the wall. Section 2540 was vertical and transverse, and 2541 was horizontal. The strike is N. 70° E., parallel to the general direction of the valley up which it continues for over a mile.

Three-fourths of a mile above the first exposure the same dike crops out again near the west end of Mr. Drew's fields. It stands out prominently, as shown in plate 6, figure 2. The strike of this roughly columnar, wall-like mass is N. 55° E. It is vertical, and 5 feet in thickness. The rock is micaceous, and although hard, is rather easily disintegrated. For this reason the rock crops out on steep slopes, where the erosion is rapid and in excess of complete disintegration; but on gentler slopes, where the disintegration is in excess of transportation, the dikes do not outcrop and cannot be readily traced. The soft shales are here well exposed directly against the dike, and show no trace of induration. The sides of the dike are somewhat firmer and the sand apparently finer than that in the middle portion. This feature has been noticed in a number of cases, and will be referred to again in considering the microscopic structure of the rock. It recalls similar phenomena frequently observed in connection with dikes of igneous rocks. The similarity is enhanced by the fact that along its borders the dike frequently includes small fragments of shale—a feature which has been observed in many

FIG. 1.—LATERAL VIEW OF WALL-LIKE SANDSTONE DIKE ON CROW CREEK. 20 FEET HIGH.

FIG. 2 -SANDSTONE DIKE FILLING A JOINT ON NORTH FORK. 4 INCHES THICK.

FIG 3—SANDSTONE DIKE WITH PARALLEL AND TRANSVERSE JOINTS ON DRY CREEK. 18 INCHES THICK.

other dikes. Although the fractures are nearly all transverse, cutting the dike into irregular blocks or columns, there are a few fractures near the edge of the dike parallel to its sides.

Fifty yards west of the large dike here exposed are the two small ones shown in plate 6, figure 1. The larger one on the left is a foot in diameter, and has well-developed parallel jointing. An important relation of the principal set of transverse joints to the bedding in the shale is well illustrated in these dikes, where it is seen that the stratification and the most conspicuous cross-jointing are parallel. Specimens 1971 and 2384 from the middle portion of the Great dike are apparently coarser grained; 1970, 2385, and 2386 are from the more compact and apparently finer-grained border. Specimen 2387 is from a little dike close by the great one, and 2388, 2389, and 2390 are from the two dikes 50 feet away.

The Great dike continues southwest across a bend of the stream, and is well exposed at 10, where plate 8 represents its appearance. It is here 5 feet in greatest width, and divides downwards into a number of smaller dikes. The finer-grained and somewhat harder edges of the mass and its cross-fractures are here well exposed. Within the shadow in the central portion of the dike there is an inclusion of shale. This included shale is soft and spheroidally weathered, exactly like that upon the sides of the sandstone dike. Scarcely a trace of jointing can be detected in the adjacent shales at this point, but at a few other localities it has been observed in connection with the dikes. The direction of the bluff here is such that the shales appear to be horizontal, but in reality they are slightly inclined. Specimen 2391 is from the lower portion of this dike, and 2392 from the included shale. Near this exposure the shales strike N. 10° E. and dip 17° to the eastward.

Continuing southwestward, the Great dike crosses another elbow of the stream and is again exposed at 11, in an abandoned placer mine, where it is 3 feet thick. Its dip is 82° S. E. and its strike N. 48° E., which carries it across the divide to Poverty gulch near Mr. Glass's, 2 miles away, where it again appears. Associated with it at 10, on Roaring river, are several smaller dikes. One is 6 inches thick; strike N. 47° E. Another is 1 foot through, and dips 77° N. W. A third is only 2 inches in thickness. Distinct traces of joints are developed here, and their strikes and dips are the same as those of the dikes; furthermore, they appear to occur in the neighborhood of the dikes only. In fact, some of the joint-cracks which escape sight at a first hasty glance, when examined more carefully are found to be filled with sand in all respects like that of the larger dikes with which they are associated. Chips may with difficulty be obtained showing one of these miniature dikes, but generally the intruded sand of the dikes separates very easily from the adjacent shales, and thin sections of the contact cannot be obtained.

Dikes of Poverty Gulch.—Poverty gulch is the next one in which the dikes are exposed south of Roaring river. A group of them crosses the gulch at 12, one and one-fourth miles above its mouth near Mr. Glass's. The largest is 20 inches in width, five average from 3 to 5 inches, and several are about 2 inches across. They are vertical, strike N. 43° E., directly in line with the Great dike just noted on Roaring river, and apparently a continuation of it.

Dikes of Aiken Gulch (Camp Creek).—The first dike seen near the mouth of Aiken gulch is the Great dike traced from Roaring river. Here it is 5 feet in width, vertical, with strike N. 40° E. The northwestern wall is somewhat irregular, sending small tongues out into the shale, and numerous fragments of the shale are included in the dike. Generally, however, the walls of the dike are sharp, well defined, and smooth, and are well exposed from top to bottom of the bank, forty feet high. The edges here, as in many of the other dikes, are apparently somewhat finer (*e. g.*, specimen 2393) than the middle portion (specimen 2394).

At 14 is a dike 8 inches in thickness, and at 15, on the north bank of the gulch, quarter of a mile above its mouth, there are six small dikes, ranging generally from 2 to 12 inches thick. One of the number increases rather suddenly to a width of 3 feet, but may not continue so large. They strike N. 40° E. Near them a number of joints are exposed, and they are exactly parallel to the dikes. A short distance further up the stream-bed, on the south bank, one of the dikes forms a good, wall-like exposure.

Dikes of Middle Fork.—Ascending Middle fork, the first dike encountered is a short distance above the mouth of Aiken gulch, where the Great dike appears in the northwest bank at 16. At 17 two 6-inch dikes cross the creek. At 18, near Miller's, the Great dike again crops out, crosses the stream, and forms a heavy wall upon the left bank. It ranges from 3 to 5 feet in thickness, strikes N. 42° E., and is cross-jointed, weathering out in large, round bowlders. Near by, upon the northwest side of the Great dike, are two small dikes, 2 and 4 inches in thickness; and upon the opposite side is another, 1 foot through. Joints appear in the shales parallel to these dikes where they cross the creek. A few hundred yards south of Miller's, on the trail leading over to John Allen's, on Dry creek, a 14-inch dike is exposed.

On the left bank of the stream the Great dike continues southwestward across a curve, reaching the stream again three-quarters of a mile above Miller's, where the greatest width of the dike, 8 feet, was observed. At this point the jointing in the dike is less regular than usual, and very small fragments of shale are included in it. These fragments are small and flat and are arranged with the scales of biotite parallel with the sides of the dike. Upon the weathered surface the shale fragments fall away and produce small pits. Near the middle the vein is somewhat banded. Here and there are small veins of calcite. Although it is well exposed upon the right bank

GREAT SANDSTONE DIKE ON ROARING RIVER. 5 FEET THICK.

of the stream, it does not continue all the way across, but is cut off by shales which crop out directly in front of the dike. Whether or not the dike was offset to one side I could not discover. Specimen 2531 was collected here.

About 300 yards northwest of the line of the Great dike, at 21, a mile above Miller's, a 5-foot dike is well exposed; strike N. 41° E. It includes numerous fragments of shale, some of which are several inches across. Two small quartz pebbles were found in this dike, but otherwise the dike material was like that in all the other dikes. The fragments of shale were not distinctly oriented in the dike and gave a prominent pitting to the weathered surface. Within fifty feet to the northwestward are three other dikes, ranging from 4 to 5 inches in thickness.

Above Miller's a mile and a quarter, Middle fork passes through a small narrows between ledges of conglomerate. At the irrigating dam just below the narrows the micaceous sandstone (specimens 2532 and 2533) interstratified with the shales and conglomerates looks very like the rocks found in the dikes. It is well exposed in a side gulch, and strikes N. 24° W., dipping 32° to the N. E. The strike and dip are not uniform here, for the conglomerate by the narrows strikes N. 37° E. and dips 47° S. E., and at another place near by the shales strikes N. 5° E. and dip 33° S. E.

Above the narrows, at 22, on the right bank of the stream, are three vertical dikes, 14 inches, 2 feet, and 3 feet, respectively, in thickness. The last apparently represents the Great dike with which it is in line, striking N. 40° E.

At 23 two other dikes appear, one of 2 feet and the other of 15 inches with offsets to the northwest as it ascends. At 24 is a 12-inch dike exposed in the bed of the stream; strike N. 39° E. A little further up Middle fork a gulch enters from the south, and in it (at 25) this dike crops out a second time with a thickness of 6 inches.

On the opposite side of the stream, at 26, is a rather heavy dike, which can be traced for 300 yards and appears to be the continuation of the Great dike. It crops out again at 27, where it is 2½ feet thick and strikes N. 45° E. Continuing to 28, it disappears in the south bank with a thickness of 1 foot. From this point to its most northeastern exposure on Roaring river is about 6 miles, in which distance there are 15 exposures of the Great dike. It may not be a continuous dike all the way. More likely it is a series of dikes very nearly in the same line.

At 27, on the southern side of the Great dike, is a small one 14 inches in diameter. Where next exposed further up the stream it is of somewhat smaller size.

At 29 are three small dikes, one of which is 6 inches and the others 2 inches each in thickness. These are followed by two 4-inch dikes at 30; and again at 31, about 4 miles above Miller's, by one 2 feet in diameter.

At 32 a 1-foot dike cuts a bluff of conglomerate. Its strike is N. 38° E., and on ascending it offsets to the northwest. At 33 are two dikes, one 14 inches and the other 6 inches through, while the dike at 34 has a diameter of 16 inches. At 35 a 12-inch dike appears and continues through three exposures, the last one at 36.

The final dike of the series on Middle fork occurs at 37, just below the cabin of J. C. Crow, two and one-quarter miles below the road crossing, and is 1 foot in diameter. The search for dikes was continued over three miles further up Middle fork, but none were found.

Dikes on Dry Creek.—On Dry creek more than twenty dikes are exposed—a larger number than on any other stream,—and they are scattered over a considerable distance.

Just below the road crossing of Dry creek, one and one-fourth miles above the mouth of Salt creek, on the north bank of the stream, are four dikes occurring at intervals for several hundred yards. The easternmost varies in width from 14 inches below to only a few inches above. As it rises through the shale bank twenty-five feet in height, it offsets several times to the eastward. Near the base of the cliff there is an offset of five feet, but the two parts are partially connected. The shales and sandstone beds at this point strike N. 29° W. and dip 24° N. E. The rock of the dike is a fine-grained sandstone, containing some mica and fragments of shale.

The next vein, three hundred feet from the first, is about a foot in thickness and strikes N. 43° E., with a slight dip to the N. W. It is wider below than above, where it cuts a number of very distinct sandstone layers without faulting.

The third vein is only 8 inches through, and strikes N. 33° E., dips 85° N. W. It is very compact and offsets, as do its neighbors, to the southeastward.

The fourth dike varies greatly in width, from 14 inches below to 3 inches in the middle, and then widens, with offsets, to 1 foot above.

At 39, by the road in the stream bed, is a 20-inch dike exposed for over one hundred feet. It is very regular, has laminated sides, and the middle portion, as in nearly all the other dikes, is broken into approximately rectangular blocks by the cross-fractures.

A short distance above the road a prominent dike appears on the south (right) bank. It is only a foot thick but very like a wall, as may be seen in the accompanying illustration, plate 6, figure 4, where a lateral view brings out the cross-fractures very distinctly. It will be seen that the transverse joints are arranged in systems. All those of the same system are approximately parallel and cut across those of other systems in a manner quite unlike the columnar jointing in dikes of igneous rocks. The greater number of the cross-joints in this dike are horizontal, but a number are apparently parallel to the beds of shale in the adjacent exposure.

Near by are five small dikes, each only a few inches in diameter, and varying considerably in strike—from N. 35° E. to N. 55° E. Ascending the stream, two small dikes, 2 and 3 inches thick, are seen at 40, two miles above the mouth of Salt creek, on the left bank; then follows a stretch of three-quarters of a mile in which none were seen.

At 41, about one-quarter of a mile below John Allen's, headquarters of the Diamond Range, three excellent dikes appear. The first is 18 inches in width, has a strike of N. 40° E. and dips 85° N. W. It is represented in plate 7, figure 3, which shows distinctly two sets of fractures common in these dikes: (1) Cross-fractures dividing the mass horizontally and vertically into

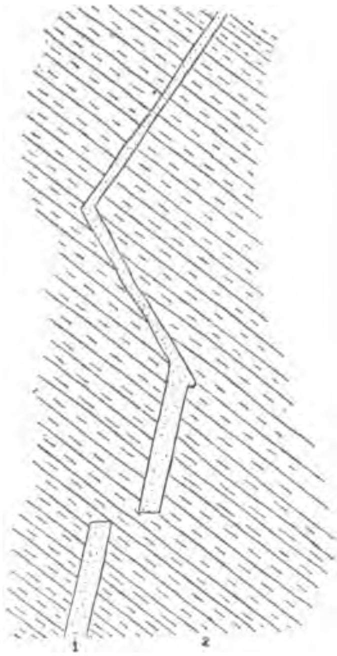

FIGURE 4.—*Crooked Sandstone Dike, 18 Inches in Thickness.*

On Dry creek, five and one-half miles above the mouth of Salt creek. 1 = Dike; 2 = Shale.

more or less regular 6-sided blocks; and (2) divisional planes parallel to the sides of the dike, separating it into thin plates. The shales here as elsewhere are neither altered nor disturbed near the contact. Specimen 2404 was collected from the edge and 2405 from the middle of this dike.

Near by is another dike of the same size and position, which is especially remarkable on account of its distinct vertical banding parallel to its sides. Similar banding has been seen in other dikes, but nowhere else so distinctly. The banding is due to the parallel arrangement of coarser and finer sand,

and the mica plates in them are all arranged parallel to the banding. Hand specimen 2406 shows the banding plainly. Section 2407 is from an apparently coarser portion in the middle. Here, too, are well seen the ripple-like marks upon the outer face of the dike. They have been seen elsewhere, especially at 48, on Salt creek, and will be referred to again. Near the same place may be seen a small dike offsetting twice to the eastward. The offsetting portions are not visibly connected.

Continuing up the stream, a 14-inch vein and several smaller ones may be observed before reaching John Allen's, three miles above the mouth of of Salt creek, At this point (42) several dikes occur in the left bank of the stream. One dike is 6 and another 4 inches in diameter, and these may be seen again a short distance to the northeast in Horse gulch, which opens into Dry creek at Allen's. One of these dikes, with a very small one near it, is displaced above to the eastward. Here, also, three small veins combine as they ascend and form a larger one.

One-fourth of a mile above John Allen's is a 14-inch dike, which in a high bank cuts fifty feet of exposed shale and can be traced across the bed of the stream and into the field for several hundred yards. Specimen 1963 is from this dike. Near by are several other small dikes.

At 44, five and a half miles above the mouth of Salt creek, two prominent dikes are exposed in the left bank of the stream. One is 18 inches in thickness and quite irregular, as shown in fig. 4. An offset occurs in the dike near the base of the, bluff, and it contains fragments of shale. This dike appears to be approximately in line with the Great dike, which was last seen on Middle fork. With this extension the Great dike has a total length of about 9½ miles.

A few yards up stream another dike occurs, 13 inches in thickness; strike N. 34° E.; dip 75° N. W. Near its edge the dike contains numerous fragments of shale. Specimen 2400 contains fragments of the shale, and specimen 2401 is from the middle of the dike. Several small dikes have been observed further up Dry creek. They are nearly in line with some of those exposed on Middle fork and serve to join all the dikes together in one large group.

Dikes of Fight Gulch.—South of Dry creek, the dikes are next exposed in Fight gulch, which opens from the northwestward into Salt creek about two and a half miles above its mouth. At 45, a 2-foot vertical dike occurs, with a strike of N. 38° E. The dike rock contains a few fragments of shale, and is full of mica which lies parallel to the sides of the dike. The sides of the dike have ripple-like marks which are nearly horizontal.

One hundred yards further down the gulch is a dike 3 feet in thickness, full of mica as the other, and with the same strike. Next comes a 15-inch dike; strike N. 45° E. It is well jointed, and has a small parallel dike close

upon one side. At 46 is a 6-inch dike, which is very lamellar, splitting parallel to the sides of the dike. Section 2524 from this dike is vertical and transverse, 2525 is horizontal, and 2526 is vertical and parallel to the sides of the dike. A 2-inch dike near by contains but little mica, and that not distinctly oriented; but in the next dike, near 47, mica is more abundant and distinctly arranged parallel to the sides of the dike. This dike is 20 inches through, and like a number of others is without any ripple-like marks upon its sides. Near by is a 2-inch dike; and three hundred yards further down the gulch a 15-inch dike occurs which is very soft and rotten, showing spheroidal weathering.

About a quarter of a mile above the mouth of the gulch the last dike was seen. It is 1 foot thick, very soft, crumbles in the hand, and is full of mica arranged parallel to the sides of the dike. Near by is an exposure of two small dikes in joints. One terminates upwards and the other downwards where the joints end.

Dikes on Salt Creek, etc.—To the southward the number of dikes gradually decreases. Ten are exposed on Fight gulch, but on Salt creek there are scarcely half a dozen. At 48, four miles above the mouth of the creek, the largest occurs. It is 3 feet in diameter, strike N. 40° E., stands vertical, and is exposed for 60 feet. Specimen 2519 was collected here, parallel to the sides of the dike, and section 2520, perpendicular. The scales of mica which it contains are arranged parallel to the sides of the dike. It is somewhat banded vertically, and its sides are rippled parallel to the line of contact with the bedding planes in the adjoining shales. The ripples are about an inch in width; their crests are somewhat rough, while the intervening portions are smooth.

Three hundred yards down the creek, at 49, is another dike, 2½ feet thick, containing an abundance of mica scales arranged parallel to its sides. The strike of the dike is N. 35° E., parallel with the course of the stream at this joint, and it is exposed at several places, showing apparently a prominent offset to the eastward. A small dike near the large one sends several lateral projections into the adjoining shales. At 50 an 18-inch dike appears, and can be traced down the creek for quarter of a mile. The ripples on the sides of the dike run vertically. Upon its northwestern side is another, about 4 inches in diameter.

At 51, opposite McNett's, a 1-foot dike appears; strike, N. 40° E. It is much fractured, showing no tendency whatever to break into regular forms.

A fourth of a mile below McNett's the shales are much disturbed, and here two small dikes occur. One of these, traversing a thin sandstone, ends above and is apparently cut off below. The other, a 6-inch dike, which splits easily into thin plates, appears somewhat as if displaced with the shales.

At 53, two and two-thirds miles above the mouth of Salt creek, is a dike 1 foot in thickness. Section 2522 from this dike was parallel with the side, and 2523 was vertical and transverse. At this point the shales disappear beneath the newer formations, and nothing more is seen of the dikes further down the stream.

The section so well exposed along Cold fork was examined, but no dikes were discovered. They do not extend so far southwest. It is likely that a few may appear in Long gulch, which my limited time did not enable me to explore.

The most southwestern dike observed was seen on the Red Bluff and Hay Fork stage road, about four miles northwest of Shiveley's (Hunter's P. O.). The dike is 2 feet in thickness, rather soft, strikes N. 38° E., and its southerly extension is offset to the northwest after the manner of the dikes on Salt creek.

General Description.

The dikes are nearly vertical, wall-like masses of sandstone, varying from a mere film to 8 feet in thickness, and cut directly through the inclined strata—sandstones and shales—of the Cretaceous group. They vary somewhat in strike from N. 20° E. in the southwestern portion of the series to N. 70° E. near the other end; and in dip are usually vertical, but they may be inclined as much as 65° to the N. W.

The great majority of them are less than a mile in length, some perhaps less than 100 yards; but the Great dike, which extends from near the mouth of Roaring river across Poverty gulch, Camp creek, and Middle fork apparently to Dry creek, has a total length of 9½ miles. At one point on Middle fork it is 8 feet thick, but generally about 5 feet.

The dikes are parallel to the joints in their vicinity, and so related to them as to indicate that the joints have not been produced by the dikes, but that, on the contrary, the position of the dikes has been determined by the joints.

The majority of the dikes observed are straight, intersecting some stream-bluff from top to bottom, affording an exposure ranging from five to sixty feet in height. By offsetting a short distance to one side or the other, the dike sometimes exhibits a more or less zigzag course both vertically and horizontally. Others appear to end abruptly before reaching the surface. Cases have been seen also where a dike apparently ended in its downward course, but such have always been found connected with other dikes. In a number of cases dikes have been noticed to combine as they ascend, but no examples of combining in the opposite direction were discovered.

The shales and sandstones in contact with the dikes are not disturbed by them nor indurated in any way as if by heat, which is frequently the case upon the borders of igneous dikes.

The dike rocks frequently contain fragments of shale. They are generally small, but occasionally as large as a hand and rarely larger. The shale fragments are usually flat and arranged with the scales of mica parallel to the sides of the dike, but this is not always so, for they may be thick, angular, and without orderly arrangement.

A common phenomenon which, however, is not universal is that the sides of the dike are more solid and apparently also of finer sand than the middle portion. Occasionally, too, the dikes are distinctly banded near the edges, and this banding is found to be due to streaks of finer and coarser sand; but it is not a conspicuous phenomenon. It may, however, be distinctly seen in a hand specimen of the rock at a distance of twenty feet.

A more important feature, and one which will be noticed more fully at another place, is the arrangement of the scales of mica in the dike parallel to its sides. In a few cases the mica scales had no definite position, but generally they are arranged as indicated and give to the rock a direction of easiest cleavage.

The dikes have two sets of fractures, one transverse and the other parallel. The transverse fractures divide the mass into more or less regular six-sided blocks, giving the dike a rudely columnar appearance. It is generally true, also, that the most abundant set of cross-joints is parallel to the stratification of the adjoining shales. The other joints, which are parallel to the sides of the dike, may be absent, and when present are usually most abundant close to the border of the dike, imparting to it a lamellar structure.

Mineralogical Composition and Minute Structure.

These dike rocks are wonderfully uniform in physical properties and composition throughout their whole extent. Upon a fresh fracture the color is gray, varying slightly in shade, but when weathered it is yellowish, owing to the presence of iron oxide.

Biotite appears to be always present, and generally in considerable quantities, so that it is one of the first minerals recognized when examining the hand specimen, but is not so abundant as to make the rock conspicuously micaceous. The rock is too fine grained to allow a further determination of the constituent minerals without the aid of a microscope.

In the thin section the rock is seen to be composed largely of quartz, feldspar, and biotite, with considerable calcite cement. Serpentine, titanite, magnetite, and zircon are less common, and other minerals are rare. Besides the fragments of simple minerals, there are numerous composite grains derived from metamorphic rocks.

The grains of quartz are usually far more abundant than any other kind, and constitute on an average (roughly estimated) about 40 per cent. of the whole rock. They are commonly angular, and rarely well rounded. In

the latter case they sometimes contain glass inclusions, showing that the grains are quartz phenocrysts derived from an eruptive rock, and may have been made round in the original mass. The angular grains not infrequently contain the minute, dark needles commonly found in the quartz of granitic rocks. Inclusions of magnetite, biotite, and zircon have also been noticed.

Both striated and unstriated feldspar are present; sometimes they are in about equal proportions, but generally the plagioclase is most abundant.

FIGURE 5.

FIGURE 6.

FIGURE 7.

FIGURE 5.—*Biotite of Sandstone Dike, crushed edgewise by the vertical movement of the sand so as to produce openings between the folia.*

FIGURE 6.—*Biotite of Sandstone Dike; the folia of one side crumpled by the upward movement of the impinging grains of sand.*

FIGURE 7.—*Biotite of Sandstone Bed, crushed perpendicular to foliation.*

The scales of biotite represented in figures 5, 6, and 7 are somewhat less than half a millimeter in length.

Occasionally the feldspar is much altered, but elsewhere it is clear with but slight trace of alteration, and between crossed Nicols shows twinning bands very distinctly. Like the quartz, the grains of feldspar are angular and show but little of the abrasion consequent upon beach action for a long time or transportation for a long distance.

The biotite is in irregular scales, often much tattered and torn in the process of transportation. As has been already noted, it is usually arranged parallel to the sides of the dikes. The scales stand on edge evidently—a position which they did not assume under the influence of gravity alone. Thin sections of the dike rock have been prepared in three directions at right angles to one another. One section was made parallel to the side of the dike; the others transverse to it, both vertical and horizontal. The sections parallel to the sides of the dike show no conspicuous arrangement of the particles, but the scales of mica are all seen broadside. In the transverse sections, both horizontal and vertical, the biotite is seen edgewise, appearing in narrow strips which are strongly pleochloric and full of cleavage lines. In the vertical transverse section the alignment of the mica scales comes out most conspicuously, and in this it may be seen that all the other mineral fragments in which one diameter is decidedly larger than the others have their longest diameters all parallel—an arrangement which may at once recall the fluidal arrangement of feldspar and other minerals commonly observed in eruptive igneous rocks.

Some of the scales of mica have been crushed edgewise in such a manner as to cause the folia to separate and form small cavities which have since been filled with calcite, the chief cementing substance of the rock. This peculiarity of the mica scales is represented in figure 5. It shows that there was motion in at least one of two directions, but does not distinguish between them. In other cases, however, there is evidence tending to show more definitely the direction of motion in the sand. In figure 6 a scale of mica is represented in which the folia upon the left side of the scale have been crumpled by the movement of impinging grains of sand. The right-hand portion of the scale has not been crumpled, and the relations of the various parts of the scale suggest that the direction of motion was from below upwards.

The scales of biotite in the dike rock are apparently identical in every way with those in the dioritic rock which is exposed northeast of Ono and forms so large a part of Bally and the Trinity mountains. This view is sustained by the presence in section 1987 of a grain of diorite in which the plagioclase feldspar and biotite are well represented.

Much of the quartz, as already remarked, comes from a similar source, and so may the feldspar; but there are many grains of a different character. There are grains of serpentine and other rocks which are distinctly metamorphic, like some of those of the Coast range. The commonest grains are composed chiefly of fine aggregate quartz in which there are minute black particles, often arranged in irregular patches or streaks. They are rarely clear and transparent, but frequently nearly so where microscopic veins of aggregate quartz cut across the larger grains. This sort of material forms a considerable portion of the rock, occurring not only in the form

of distinct grains, but also as finer material mingled with the cement in the interstices of the larger grains in such a way as to suggest at times that it is a part of the cement and deposited since the formation of the dikes. As there are no quartz veins found about the dikes, excepting the extremely minute ones which traverse in each case only a single grain of sand such as is derived from metamorphic rocks, it is believed that the dike rocks have not received deposits of silica from solution in circulating waters. The cementing substance of the rock is carbonate of lime, which is abundant in the adjacent shales and forms larger or smaller parts of all the sandstone dikes, occasionally occurring as small veins. Grains of eruptive rocks are very rarely observed. In section 2378 is a fragment of hornblende andesite.

Some associated Cretaceous Sandstone Beds.

Some of the fine-grained sandstones clearly interstratified with the shales of the Horsetown and Chico beds contain scales of mica, and in nearly every respect excepting mode of occurrence so closely resemble the dike rocks that hand specimens of the two cannot be readily distinguished without the aid of a microscope, and even then it is often impossible. Such sandstone beds are, however, not common. They have been observed on Byron creek at the top of the cascade, half a mile above Ono. Their strike is N. 10° E., dip 20° S. E. Specimens 2548, parallel to the bedding, and 2549, perpendicular to it, were collected here. They occur also two miles north of Ono, on the road to Igo, where the rock is very micaceous and rests directly upon the dioritic rock from which it has been derived; strike N. 40° E., dip 22° S. E. Specimen 1991 was collected at this locality.

Similar rocks were observed at the dam on Middle fork, where specimens 2532, parallel, and 2533, perpendicular to the bedding, were collected. The strike is N. 24° W., and dip 32° N. E. On Dry creek, 3 miles above A. Allen's, specimen 2514 was found. Such rocks occur also on Salt creek, half a mile above Martin's, with a strike of N. 30° to 37° W., and dip 23° to 30° N. E. Specimen 2517 was collected at this locality. The last locality to be mentioned is on Middle fork, a mile above its mouth, where specimen 2537, which is quite full of mica, was found.

The locality last named is to the eastward of any of the dikes, and stratigraphically above them. The beds on Salt creek and at the dam on Middle fork are penetrated by the dikes apparently without change, but those of the other localities which lie northwest of the dike area dip easterly towards the dikes and may possibly reach them at considerable depths beneath the surface.

The mineralogical composition and structure of all these sandstone beds is essentially the same. In composition, also, they resemble the sandstone dikes, but in minute structure they differ in an important respect: In the sandstone

beds as in the dikes, the mineral fragments lie with their long diameters parallel; furthermore, they are in the bedding plane. The scales of mica are all parallel, and when viewed edgewise, in general arrangement they look like those in the sandstone dikes; yet there is an important difference. Their parallel arrangement in the two cases is the result of very unlike conditions. The particles of sand, subsiding under the influence of gravity alone, lie upon their flat sides, and in this manner all become parallel in the sandstone bed and lie in the plane of stratification. A large particle of mica at first straight lies horizontal, stretching perhaps over several grains of other mineral. Other grains in turn fall upon it, and being pressed down by accumulating sand above, indent or bend the mica and make it conform to the irregular outlines of the adjacent grains as in figure 7. In sedimentary rocks, where the scales of mica are crushed in the process of deposition in water, the crushing takes place perpendicular to the plane of foliation in the mica, and does not ordinarily produce openings between the folia; but in the sandstone dikes the mica was crushed parallel to the plane of foliation as represented in figures 5 and 6.

Chemical Composition of the Sandstone Dikes and Beds.

Chemical analyses have been made of five specimens of sandstone from dikes which are widely separated and equally distributed throughout the field. The results are as follows:

Chemical Analyses of Sandstone Dikes and Beds.

Number of analysis.	1.	2.	3.*	4.*	5.*	6.	7.	8.*
SiO_2 . . .	48.13	48.10	59.10	61.60	54.55	55.85	67.62	60.74
TiO_2 . . .	.24	.47	.70	trace	trace	.76	.48	.86
P_2O_5 . . .	.14	.13	trace	.08	.10	.18	.08	trace
Al_2O_3 . . .	11.19	12.16	14.02	12.15	10.64	13.20	13.63	10.25
Fe_2O_3 . . .	1.25	1.02	3.16	2.09	1.59	2.56	1.25	4.31
FeO . . .	1.47	2.14	1.42	3.30	1.16	4.77	3.27	6.21
MnO . . .	.29	.26	trace	trace	1.53	.24	.15	trace
CaO . . .	16.39	15.88	9.35	6.92	14.30	6.93	2.80	4.97
BaO . . .	.04	undet.	. . .	. . .	. . .	undet.	.03	. . .
MgO . . .	2.22	1.65	1.72	2.33	1.29	1.90	2.34	3.69
Li_2O . . .	. . .	. . .	none	none	none	. . .	. . .	none
K_2O . . .	1.17	1.56	1.49	1.41	1.68	1.89	1.11	.52
Na_2O . . .	2.29	2.46	2.21	2.16	2.60	2.60	2.78	1.83
CO_2 . . .	12.73	10.36	4.65	5.05	9.05	4.97	.72	2.29
SO_3 . . .	. . .	. . .	trace	.27	.10	. . .	. . .	.40
Cl. . . .	. . .	. . .	trace	trace	.09	. . .	. . .	trace
H_2O at 110°.	.78	.46	. . .	. . .	. . .	1.13	.64	. . .
" red heat.	1.78	3.27	2.63	3.10	1.60	2.29	2.83	4.36
	100.11	99.92	100.45	100.46	100.28	99.97	99.73	100.43

* The material of Nos. 3, 4, 5, and 8 was dried at 104° C.

Description of Specimens.

No. 1.	Sandstone dike	on Salt creek, ½ mile above McNett's.	Locality 50.
2.	" "	1¼ miles below Ono bridge, on North fork of Cottonwood.	" 1.
3.	" "	¼ mile below John Allen's, on Dry creek.	" 41.
4.	" "	" " " "	" "
5.	" "	at John Allen's, on Dry creek.	" 42.
6.	" bed	at dam on Middle fork, 1 mile above Miller's.	" 21.
7.	" "	top of cascade, ½ mile up Byron creek from Ono.	
8.	" "	2½ miles above John Allen's, on Dry creek.	" 44.

Of the foregoing analyses numbers 1, 2, 6, and 7 were kindly made for me by Mr. Thomas M. Chatard, and numbers 3, 4, 5, and 8 by Mr. J. Edward Whitfield, in the chemical laboratory of the U. S. Geological Survey.

The range of silica in the dike rocks is from 48.10 to 61.60, while in the bed rock it is from 55.85 to 67.62, with a considerably higher average amount than in the dike rocks. The same is true to some extent of the oxides of iron. These are fully counterbalanced by the lime and carbon dioxide, which shows that the lime carbonate is more abundant in the dikes than in the beds—a fact which is apparent also under the microscope. The carbonate of lime is the cement and, being a secondary deposit, should not be considered a constituent of the original sand. It has already been shown that in mineralogical composition the dikes and certain bed rocks are practically identical, and the chemical analyses illustrate the same fact.

Geologic Relations and Origin of the Sandstone Dikes.

Position and Age.—From the geologic map, figure 2, in which the distribution of the dikes is shown, it will be seen that they are confined to the Cretaceous—Horsetown and Chico beds. Figure 8 is a cross-section of the same region, and shows in a general way the relations of the rocks from Bully Choop in the Coast Range on the northwest, to the Sacramento valley on the southeast. They are naturally separated into four groups of formations: (1) The Metamorphic rocks of the Coast Range; (2) the Cretaceous formations of the Bald hills, which are marked by an old base level of erosion and composed of conglomerates, sandstones, and shales of the Horsetown and Chico beds; (3) the sandstone dikes which penetrate these beds; and (4) the tuff, gravels, sands, and clays of the newer formations which lie in the Sacramento valley.

The Cretaceous group of strata appears to be a continuous, conformable series, thousands of feet in thickness. The basal bed, well exposed on Eagle, Byron, and Jerusalem creeks, is a heavy conglomerate of coarse, round and sub-angular fragments derived directly from the older metamorphic rocks, upon which it rests unconformably, and marks approximately an ancient shore line of Cretaceous time.

The strata of the lower portion of the group lying on the North fork of Cottonwood creek above the mouth of Hulen creek contains an abundance and great variety of fossils, regarded by the California Geological Survey and Dr. C. A. White as belonging either wholly or in large part to the Horsetown beds. At the mouth of Hulen creek the Chico beds, characterized by many fossils, occur and extend eastward, passing beneath the later formations of the Sacramento valley. Near the western limit of the newer formations, the Chico beds are penetrated by the sandstone dikes already described.

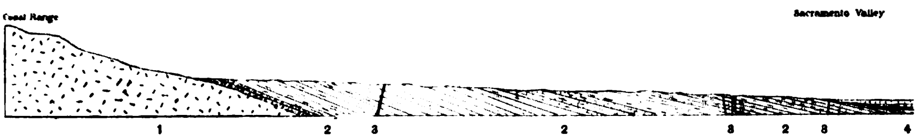

FIGURE 8.—*Section across the Dike Region along the North Fork of Cottonwood Creek, in Shasta County, California.*

1=Metamorphic and dioritic rocks of the Coast Range; 2=Cretaceous conglomerates, sandstones, and shales; 3=Sandstone dikes; 4=Newer formations of the Sacramento valley. There may be an unconformity near the middle of the section.

Their vertical position indicates that they were formed after the tilting of the Chico strata, and the fact that they are overlapped by the Salt creek and Tuscan formations demonstrates their existence before these formations were developed.

After the tilting of the Chico beds, their upturned edges were worn off to a general level, a base level of erosion; and in this process the tops of the dikes were removed also, showing that they were formed between the times of the tilting of the Chico group and the development of the base level of erosion across the Cretaceous belt. The Chico beds are the top of the Cretaceous, and the dikes which penetrate them could not have been formed before the close of the Cretaceous. The formations of the Sacramento valley which are younger than the dikes are Pleistocene, and in part probably Neocene, rendering it altogether probable that the dikes were formed sometime during the Eocene or Neocene.

The Dikes occupy Joint Fissures.—Joints are uncommon and poorly developed in the Cretaceous shales. They were seen chiefly in the vicinity of sandstone dikes. The latter occupy fissures between joint planes, and it is evident that the position of the dikes was determined by the joints. It may

well be that the joints were formed at about the same time as the dikes, both being results of the same general cause; but it is clear that the joints were formed before the dikes, and that the dikes may be regarded simply as large joint fissures filled with sand. There is a complete gradation in the size of the dikes, from a mere film in a joint, as shown in plate 1, figure 3, up to 8 feet in thickness.

Method of filling the Fissures.—Fissures in rocks may be filled with matter brought into them in the gaseous, liquid, or solid state. When filled by the crystallization of minerals from a gaseous or liquid condition, either that of solution or fusion, the rock produced in the fissure must be more or less crystalline and easily distinguished from one formed by filling a fissure with solid particles or fragments of minerals. In the first case the mineral or minerals crystallize in place, and if there is no interference in the process crystals will develop more or less perfectly, as in the rocks of many igneous dikes. Each particle is bounded either by crystal planes or less regular outlines of growth due to interference in crystallization which impart a characteristic, non-fragmental structure to the rock in which it occurs.

On the other hand, if a fissure were filled with particles of solid matter, as for instance sand, and the whole were cemented so as to form a hard dike rock, it would have a decidedly fragmental character. A microscopic examination would certainly show that the mineral particles or grains in the rock are not bounded by crystal faces or lines of growth, but instead by lines of fracture and abrasion. In the first case the crystals, whether perfect or not, are as large as they ever were; but in the second case the grains are only fragments of broken crystals, and the term fragmental defines the characterizing feature of the rock.

From these considerations it would appear to be an easy matter to distinguish a rock formed in a fissure by filling it with material brought thither in a liquid state, either of solution or fusion, from one produced by filling a fissure with solid particles subsequently cemented; and such is really the case. The dike rock already described is plainly fragmental, and there can be no reasonable doubt whatever that the fissures were filled with sand.

The question at once arises, Whence came the sand? It could not have come from the bounding rocks of the dike upon the sides and ends upon the surface, for so far as can be seen, they are almost always shales. It must have entered the fissures either from above or below.

If we suppose they were slowly filled from above * by loose sand brought thither by wind or water and dropped under the influence of gravity alone, the long and broad but thin grains, like scales of mica and other more or less foliated minerals, would generally lie horizontal, as they lie parallel to

* Professor R. D. Irving describes sandstone "veins" on the shores of Lake Superior, formed by filling fissures from above: U. S. Geological Survey Monograph V, Washington, 1883, pp. 139–'40 and 292–'3.

the planes of stratification in micaceous sandstone, and would stratify the dike transversely. It h[illegible]hown, however, that the scales of mica in the dikes do not lie horizontal but stand on edge vertically, parallel to the sides of the dikes, and that the banding which is in several dikes very distinct has the same position. It is evident from these facts that the fissures were not filled from above by ordinary sedimentary processes, but that the sand was forced into them.

The arrangement of the scales of mica parallel to the sides of the dike is the one of least resistance, and is a natural consequence of the motion of the sand as a body in the fissure. It appears to be analogous to the fluidal arrangement of crystals in eruptive rocks. So far as the position of the mica and the banding are concerned, the motion may have been in any direction within the plane of the dike.

That the sand has actually been forced into the fissures is shown by the effects produced upon the form of the scales of mica. Attention has already been called to the fact that many scales are crushed edgewise, as represented in figure 5. In this case the direction of motion is not evident, whether upwards or downwards in the dike. For the purpose of discovering evidence concerning the direction of motion in the sand, three thin sections (one horizontal, another vertical and transverse, and a third vertical and parallel to the dike) each were prepared of a number of dikes, and a study of them has thrown considerable light upon the subject. It is easy to understand that owing to the friction upon the walls of the fissure the sand in the middle would move more rapidly than that upon the sides, and in this way a shearing strain would be set up in the grains by their mutual attrition. If this strain distorted the grains it is evident that the form of the distortion, considering also its position in the dike, would indicate the direction of flowing in the sand. In one of the vertical transverse sections the phenomenon represented in figure 6 was observed, and conclusively demonstrates that the motion of the sand in filling the fissures and forming the dikes was from below upwards.

It must not be forgotten, however, that the vertical position of the mica scales, as in many metamorphic rocks, and the banding also, could probably be produced by movement in the mass as a result of lateral compression after the fissures were filled with loose sand. But there is no need of appealing to lateral compression, for the movements at the time the fissures were filled will explain all the appearances.

A number of dikes fail to reach the surface, and others are offset in such a manner that it would seem impossible to fill the fissures from above. These facts strongly support those already adduced, and render it certain that the sand was forced up from below to fill the fissures.

It is well known that all rocks a short distance beneath the surface, within the accessible portion of the earth's crust, contain water, and that the amount that each contains is in a general way proportional to its porosity. It is evident, therefore, that the loose sand which filled the fissures from below, being very porous and bounded chiefly by shales which have a much lower degree of porosity, must have been saturated with water.

It appears that if by any means a fissure were suddenly formed from the surface down to the sand saturated with water the latter would rise in the fissure and, if the hydrostatic pressure were sufficiently great, the water would rush forth, carrying the sand with it to fill the fissure and, like an artesian well, overflow upon the surface.

With a view to determining the possible influence of the fractured strata in filling the fissures, Mr. J. Stanley-Brown made for me the series of specific gravity determinations noted in the following table:

Specific Gravity of Dike and Bed Rocks.

Localities.	Specific gravity.	Average.
SHALES PENETRATED BY THE DIKES—		
Dry creek, at A. Allen's	2.7346	2.7360
North fork of Cottonwood, 1 mile above Gas Point	2.7374	
SANDSTONES OF BEDS—		
Dry creek, 3 miles west of A. Allen's	2.6706	2.6750
Dam on Middle fork, 1 mile above Miller's	2.6896	
Top of cascade in Byron gulch, ½ mile above Ono	2.6520	
SANDSTONES OF DIKES—		
Fight gulch	2.6834	2.6876
Dry creek, 1¼ miles above mouth of Salt creek	2 6858	
" " " " " by the road	2.6745	
Three-quarters of a mile up Middle fork from Miller's	2.7006	
North fork of Cottonwood, ¾ mile below mouth of Eagle creek	2.6940	

The specimens used in the determinations were cut and ground in the form of cubes with round edges, and at the beginning and end of the observation were dried to a constant weight. The weighings were made directly in water by means of a fine wire support and the result reduced, according to Kohlrausch's formula, to 4° C.

The sandstone of the dikes appears in the average to be slightly heavier than that of the beds—a fact which may be due to the greater abundance of biotite in the dike rocks. At the time the fissures were filled, however, the loose sand must have had a lower specific gravity than now, for the spaces between the grains which were filled by water or air are now occupied by carbonate of lime. The shales are appreciably heavier than the sandstones, and, since they constitute the great mass of the country rock of the dikes, by their weight alone they may have aided in forcing the watery sand into

the fissures and perhaps out upon the surface; but the greater influence in producing these results is to be accorded apparently to hydrostatic pressure.

Phenomena commonly associated with Earthquakes.—The phenomena just mentioned are such as are frequently associated with earthquakes. We are all familiar with the fissures and craterlets of the late Charleston and Sonora earthquakes, where the sand and water issued so copiously, in some cases for several days after the earthquake. But that we may not seem too hasty in referring the sandstone dikes to earthquakes, let us examine the records of such seismic movements and briefly note some of their effects.

During the great Calabrian earthquake of 1783 many fissures were formed in the ground, and from some of them great quantities of sand and water issued. After the flow ceased the openings were left full of sand. In our own country the fissures formed by the earthquake of New Madrid, Missouri, in 1811–1813, were still plainly visible in 1846 when Sir Charles Lyell visited the scene. He says that they were often parallel, and yet there was considerable diversity of direction, varying from N. 10° to 45° W. Many were yet traceable for half a mile and upwards. It is said that during the earthquake, powerful jets of water filled with sand and coaly matter issued from these fissures; and distinct traces of them could be seen after the lapse of thirty-four years. Similar phenomena accompanied the earthquake of 1819, at the mouth of the Indus. In all the cases already cited the fissures were in unconsolidated material only.

During the earthquake of Valparaiso in 1822, however, parallel fissures were formed in the solid granite of the coast, and could be traced inland for 1½ miles. Cones of sand 4 feet in height were formed in several districts by the water, and sand forced up from below through the fissures to the surface. More profound fractures were associated with the great earthquakes of New Zealand in 1848 and 1855. After the first, a fissure averaging 18 inches in width could be traced sixty miles. At the time of the second, a fault was formed with a displacement of nine feet, which could be traced for a distance of ninety miles.

At the time of the Sonora earthquake, May 3, 1887, there were, according to Mr. Goodfellow,* extensive irruptions of water and sand from the fissures formed in connection with the earthquake. These fissures could be traced more or less continuously for a distance of fifty miles. They mark the line of a fault, the average displacement of which for the whole distance was eight feet. It is inconceivable that such profound fractures should affect the thin covering of soil only; they must extend as well into the solid rock beneath.

The fissures and craterlets formed in connection with the Charleston earth-

*Science, Aug. 12, 1887, vol. X, p. 81.

quake are well known. It is interesting to note that the sand brought up to the surface at that time was, in some cases at least and perhaps in many, decidedly micaceous, even more so than that in the sandstone dikes.

Of the mineral particles usually found in sand the scales of mica are most easily transported by water. This fact is sometimes made use of in petrographic laboratories to separate mica from other minerals in rock powders by causing water to flow up through the rock powder, regulating the current so that it will carry up the mica and allow it to escape above through an outlet, while the other portion of the powder remains behind. The tendency of this sort of action in filling earthquake fissures would be to render the sands brought up to the surface more micaceous than those which remained behind.

The formation of a system of parallel fissures by earthquakes and filling them with sand forced up from below is a common phenomenon, and in all essential features apparently identical with the formation of the sandstone dikes described in this paper. It is reasonable, therefore, to regard these dikes as a record of ancient earthquake movement.

The Region is favorable for the Production of such Phenomena.—The region of the dikes is one of earthquakes, also; and, when we consider its geologic structure and compare it with that of countries where earthquakes have produced such phenomena, it is found to be well adapted to yield the same results. Dolomieu's description of the country affected by the great earthquake of 1819 about the mouth of the Indus would in a general way answer very well for the northwestern portion of the Sacramento valley. The Cretaceous strata, as we have seen in the section figure 8, are so situated as to catch and hold great quantities of water flowing eastward from the Coast Range. Many of the streams sink in crossing the Cretaceous belt, and the sandstone beds, before they were indurated, must have been completely saturated with water and ready to rush forth under the influence of an earthquake to fill fissures in the soft strata with sand.

Source of the Sand in the Dikes.—It has been already remarked that certain sandstones of the Cretaceous belt are very like those of the dikes. The one to which there is the greatest similarity is near the top of the cascade on Byron creek, half a mile west of Ono. It is a stratum somewhat less than 100 feet in thickness, with a strike N. 10° E. and dip 20° toward the Sacramento. Elsewhere its strike is more to the eastward, nearly parallel with the western limit of the Cretaceous terrane, and the average dip is about 15°. The sandstone bed outcrops about seven miles westward of the principal group of dikes, and dips toward them at an angle of 15°. If its dips remain constant as to direction and angle, as there is reason to believe, and there is no faulting, the bed must be in the neighborhood of 10,000 feet below the

surface where the dikes are exposed. The westernmost dike crops out on the North fork, just below the mouth of Eagle creek. It must reach the same stratum at a much less depth, probably within 2,200 feet of the surface.

These figures do not appear to be unwarrantably large, and yet when we compare them with what is actually known of the depths of earthquake fissures they seem very deep. Their horizontal extent, however, is not incompatible with great depth, for one of them is certainly not less than six miles in length and from 5 to 8 feet wide.

Origin of the Joints in the Dikes.—The peculiar jointing in the dike requires explanation. It may be accounted for in the following manner: The parallel jointing is developed in these dikes only where the minerals have a most decided flow arrangement, and the jointing is parallel to this alignment. It is a feature which may be well seen in hand specimens. The direction of the jointing is determined by a sort of slaty cleavage; but the fissures are actually developed along these lines of minimum cohesion, probably by shrinkage.

The transverse joints are of a different nature. Generally, but not always, the principal system of transverse joints in the dikes is parallel to the stratification of the adjoining shales and sandstones, so that it is evident that the planes of stratification have some influence in determining the position of the principal transverse joints. The different strata touching the dike would vary greatly in porosity. Some being open would take up water rapidly, and the water would be drawn toward the porous strata on both sides of the same plane of stratification. The shrinkage in the dike from the loss of water would produce a strain at right angles to the stratification, and when the strain becomes greater than the cohesion of the dike it cracks transversely, parallel to the strata. Occasionally, as in the large dike on Crow creek (plate 7, figure 1), this system embraces nearly all the transverse fractures of the dike. Others associated with them may be at right angles to and a natural consequence of the first, but there may still be other sets whose origin as shrinkage cracks is not so evident.

The only other change which has taken place in the dikes since their formation is the deposition of carbonate of lime, which has cemented the sand firmly together, so that the sandstone of the dike usually has greater solidity than that of the beds. This larger amount of carbonate of lime in the dikes is clearly shown by the chemical analyses.

Distribution of the Dikes, considered as Earthquake Phenomena.—The general distribution and parallelism of the dikes may be seen in figure 2. Only the dikes 18 inches or more in width have been represented. The various exposures which appear to be of the same dikes have been connected. Only the width of the dikes has been exaggerated. The dotted line to the right

of the dikes represents the western limit of the newer formations of the Sacramento valley, beneath which some of the dikes disappear. The largest dike on the North fork stands alone. The three large ones on Crow creek have been connected with their smaller representatives on the North fork a mile above Gas Point. The Great dike extends from Roaring river to Dry creek, a distance of 9½ miles. Near the western border of the Great dike on Middle fork, at the dam, is another dike 5 feet in thickness, but it is comparatively short. Three dikes on Dry creek, Fight gulch, and Salt creek have been connected as the exposures appear to warrant. These dikes are thicker on Fight gulch than on Dry creek, indicating that they are thinning out and probably do not extend very far beneath the newer formations.

The general parallelism of the dikes is well shown, although there is a divergence of 51 degrees in their strike, ranging from N. 20° to 71° E. The average strike on the North fork is N. 47° E.; on Crow creek, N. 54° E.; on Squaw creek, N. 53° E.; on Roaring river, N. 54° E.; in Poverty gulch, N. 43° E.; in Aiken gulch, N. 40° E.; on Middle fork, N. 42° E.; on Dry creek, N. 40° E.; in Fight gulch, N. 40° E.; on Salt creek, N. 34° E.; on the Stage road, N. 38° E. The average strike of all north of Aiken gulch is N. 49° E., and south of it N. 39° E. The more easterly trend of the northern dikes may be seen in the accompanying map. The same bending to the eastward may be observed in the Great dike. On Roaring river its average strike is N. 57° E., the lowest being N. 48° E. On Middle fork its average is N. 41° E., and the highest N. 45° E.

If we regard these dikes as earthquake phenomena their gentle curvature may indicate their relation to the center of disturbance far to the southeastward in the Sacramento valley. The fissures do not appear to belong to the Sonora or Owen's valley type, in which case the fissures follow the base of a mountain range and are associated with faulting. In this case the fissures are some distance from the base of the Coast Range, and no faulting has been observed.

Crosby's Theory of the Origin of parallel Joints.—The theory proposed by Mr. W. O. Crosby * to explain the origin of parallel joints is of interest in this connection. He regards them as fractures produced by earthquakes, and the theory has much in its favor. It is strongly supported by the phenomena here described. The joints in the shales are generally most noticeable in the neighborhood of the dikes, and the dikes themselves occupy joint fissures which must have been formed at about the same time and by the same general movement as the dikes. Wide fissures, if left empty in soft strata under pressure, would not remain open; their sides would gradually come together.

* Proceedings Boston Soc. Nat. History, vol. XXII, p. 72.

Sandstone Dikes observed in other Localities.

On the voyage of the Beagle in the winter of 1833–'34 Darwin observed three vertical dikes composed of fragmental material some miles up the harbor above Port Desire, Patagonia. He says:

"The first is straight, with parallel sides, and about four feet wide; it consists of whitish, indurated tufaceous matter, precisely like some of the beds intersected by it. The second dike is more remarkable; it is slightly tortuous, about eighteen inches thick, and can be traced for a considerable distance along the beach. It is of a purplish-red or brown color, and is formed chiefly of *rounded* grains of quartz, with broken crystals of earthy feldspar, scales of black mica, and minute fragments of claystone porphyry, all firmly united together in a hard sparing base. The structure of this dike shows obviously that it is of mechanical and sedimentary origin; yet it thinned out upward and did not cut through the uppermost strata in the cliffs. This fact at first appears to indicate that the matter could not have been washed in from above; but, if we reflect on the suction which would result from a deep-seated fissure being formed, we may admit that if the fissure were in any part open to the surface mud and water might well be drawn into it along its whole course. The third dike consists of a hard, rough white rock, almost composed of broken crystals of glassy feldspar, with numerous scales of black mica, cemented in a scanty base. There was little in the appearance of this rock to preclude the idea of its having been a true injected feldspathic dike." *

In July, 1841, Professor J. D. Dana discovered a series of sandstone dikes at Astoria, near the mouth of the Columbia river, Oregon.†

According to Professor Dana—

"Half a mile above Astoria a sandstone dike five feet wide intersects the bluff from top to bottom, and may be traced following an east by south course across the flat shores to the edge of the river. The rock resembles a half decomposed granite, and seemed at first to be an instance of granite intersecting Tertiary shale. But further examination proved it to be identical with the granitic sandstone of the opposite shores of the Columbia. Large fragments and chips of the adjoining argillaceous beds are imbedded in the sandstone of the dike."

Four other sandstone dikes were observed, ranging from 5 to 18 inches in width, "and they are generally faulted." Professor Dana remarks:

"These pseudo-dikes of sandstone, were probably formed after or during the deposition of the sandstone while the region was yet under water. Fissures were opened perhaps by the same cause that ejected the basalt of the intersecting dikes, and the fissures were filled at once by the granitic sands, along with an occasional fragment of shale from the walls of the fissure. Their number and irregularity evince that these regions have been often shaken by subterranean forces."

* Geological Observations on Coral Reefs, Volcanic Islands, and on South America, 1851, Part III, p. 150. In the same volume, part II, p. 100, Darwin mentions dikes of tuff traversing strata of the same material.

† U. S. Exploring Expedition, under command of Ch. Wilkes, vol. X, Geology (by J. D. Dana), p. 654.

J. D. Whitney, in his Geology of California, vol. I, p. 40, says that at Lone Tree cañon, about seven miles southeast of Corral Hollow, California, "masses of sandstone were found in the shales in the same position with reference to the surrounding rocks as would be occupied by dykes. These dyke-like masses seem to have originated in the filling of fissures by sand which has since become indurated." Professor W. H. Brewer, who appears to have made the observations upon which Professor Whitney's statement is based, discovered these dikes in middle California nearly thirty years ago; and it is probable that others will be found in that country of earthquakes.

Several years ago Mr. C. D. Walcott collected, near Lake Champlain, a specimen from what he at the time regarded as a dike cutting limestone. We were much surprised at the time upon examining a thin section of the rock to find it sandstone. In general it resembles the sandstone dike rock of California, but none of the few scales of mica in the section were found to be crushed.

Several weeks ago Mr. W J McGee discovered a number of small sandstone dikes intersecting the Eocene Buhrstone at Corinne, in eastern-central Mississippi. Mr. McGee kindly permits me to announce this interesting find, and has furnished material for examination not only from the dikes but also from their country rock. One dike is 8 to 12 inches in thickness, and another is 4 inches. Specimens were collected from both dikes. They are distinct sandstones to the naked eye, light-colored, almost white, excepting where stained yellow by oxide of iron. In the thicker dike the sand is firmly lithified, while in the thinner it is rather friable. Both sides of the thicker dike are "distinctly slickensided vertically," though there is no perceptible displacement of the strata in the country rock.

The most conspicuous mineral in the hand specimens of these dikes, as in those of California, is mica. In California it is biotite, but in Mississippi it is muscovite. Another feature which may be seen in the hand specimens is that the scales of mica are all approximately parallel, not only among themselves, but also with the side of the hand specimen which Mr. McGee informs me was the side of the dike.

Thin sections were prepared of the dike rock in two directions perpendicular to each other and both at right angles to the sides of the dike. The rock, is composed chiefly of grains of quartz sand, which in many cases have been partially rounded. It is of the kind of quartz that is common in granitic rocks and occasionally contains minute scales of biotite and small dark needles which are well known in granitic quartz. One grain was observed apparently with several glass inclusions, such as are known in the quartz of eruptive rocks only. Occasionally grains of tourmaline are found intermingled with the quartz.

Muscovite, although rather plentifully present, is far less abundant than

the quartz, and shows slight traces of lateral crushing. In many cases the folia are parted and the space between them occupied by cement, as in the California dike rock. The alignment of the particles and their distortion is not quite as conspicuous as in the dikes already described, but yet it is sufficient to clearly indicate the character of the movement by means of which the fissures were filled with sand.

Of the country rock examined, none of the samples closely resemble the sandstone of the dikes which, like that in California, is quite constant in its character. One specimen of the four from the Eocene Buhrstone of the same locality contains scales of muscovite, but the rock generally is of finer texture than that in the dikes.

SUMMARY.

The sandstone dikes upon the forks of Cottonwood creek along the northwestern border of the Sacramento valley in California are over forty five in number, and crop out at about 112 exposures throughout an area fifteen miles in length from north to south and six miles in average width.

They are all approximately parallel, with an average strike throughout the whole area of N. 44° E.

They are usually vertical, ranging from a mere film to 8 feet in thickness and from 200 yards to 9½ miles in length.

They intersect the Cretaceous sandstones and shales along joints, without distortion or displacement of the strata, and occasionally include numerous fragments of the shale.

They are sometimes banded vertically parallel to their sides, and the scales of mica and other lamellar fragments usually stand on edge in the same plane.

The dikes are traversed by joints in two principal directions, parallel and transverse. Unlike the columnar jointing in igneous dikes, the groups of transverse joints in the sandstone dikes cross one another directly; and the principal group is usually parallel to the stratification of the adjoining shales.

The dike rock is an impure quartz sandstone containing considerable biotite. The structure of the rock is unquestionably fragmental, and shows no trace of crystallization in place of any material excepting the cement, which is carbonate of lime.

Much of the biotite is crushed in the direction of foliation, that is vertically in the dike, since the scales stand on edge and the distortion of the particles is such as to indicate that the sand moved upward in filling the fissure.

Filling fissures in the earth with sand from below is a common consequence

of earthquakes—natural phenomena which are by no means rare in California.

The geologic structure of the region is such as to render it especially favorable for the production of sandstone dikes by means of earthquakes; and the evidence appears to be conclusive that these dikes record seismic movement during the Tertiary.

DISCUSSION.

Professor W. M. Davis.—In confirmation of Mr. Diller's suggestion that detrital material supplied from above would take a horizontal stratification as it settled into a fissure, I may make reference to the several vertical fault-fractures in the city trap-quarry, at Meriden, Connecticut. These fractures traverse a sheet of lava and are chiefly filled with angular trap-fragments, but the interstices are occupied with sandstone, not in fragments as if it had fallen in with the pieces of trap, but in a close-fitting mass, as if it had settled down in the form of separate particles derived from the sandstone originally overlying the trap-sheet, thus, in a general way, taking a structure conformable to the blocks of trap that it surrounds, but showing also a tendency to a transverse or horizontal stratification. It seems probable that these fissures were filled gradually by infiltration from above, while those that Mr. Diller describes were filled suddenly by violent pressure from below.

Professor B. K. Emerson: I wish to describe in a word an abnormal vein filling which, though occurring on a small scale as compared with the remarkable cases just described, may have some resemblance in origin. The till in the Connecticut valley often requires blasting; and in a deep cellar excavated in this way a great horizontal sheet of sands nearly two feet thick and above sixty feet long was exposed, covered by twelve to twenty feet of the most compact till and separated by two feet of the same firm till from a heavier bed of buff sands, which was underlain by the till in great thickness. The upper sheet of sand had plainly been moved into its place as a frozen block separated from the lower sand, and it terminated abruptly on all sides in the till.

Starting in the lower sand, a fissure had formed, running up through the two-foot band of till and the sand bed, and penetrating two or three feet into the upper till, then tapering to a point. This fissure was filled with fine clay, arranged in layers matching each other and all parallel to the walls of the fissure. It seems plain that the whole mass must have been rent by some strain due to the motion of the ice while it was itself frozen, and that by hydrostatic pressure the fissure was filled with mud or muddy water from below, and that this occurred with several intermissions to effect the banding of the vein.

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TERTIARY AND CRETACEOUS DEPOSITS OF EASTERN MASSACHUSETTS.

BY N. S. SHALER.

(*Read before the Society December 26, 1889.*)

CONTENTS.

GENERAL STATEMENT.

In a memoir on the geology of Martha's Vineyard contained in the 7th Annual Report of the Director of the U. S. Geological Survey, I gave a preliminary account of the several deposits, mostly of doubtful age, exhibited on the western part of that island. The conclusions there presented were in the main those which had been derived from a study of the district in the years between 1860 and 1872. Since this memoir went to press, I have been able considerably to extend my studies in this field. A portion of the results of this latter work are embodied in a recent paper entitled, "On the Occurrence of Fossils of Cretaceous Age on the Island of Martha's Vineyard, Mass."* In that paper I have endeavored to prove the existence of middle or lower Cretaceous deposits in the central portion of that island. About 15 species of fossils are there described as occurring in this deposit, two of which, an *Exogyra* and a *Camptonectes*, appear to afford indubitable evidence as to the Cretaceous age of the beds.

In all my previous studies in this field it has been difficult to prepare well determined sections of the principal outcrops for the reason that these occur on the sea shore and had been extensively covered by rubbly material which had gradually accumulated. In the autumn of 1888, a rain storm of great violence, which led to the deposition of about five inches of water in the course of two hours, scoured off these escarpments in such a manner as

*Bulletin Mus. Comp. Zool., vol. XVI., No. 5, 1889.

to reveal the position of the beds in the sections at Gay Head and elsewhere in a far more satisfactory manner than they have been exhibited during the past 30 years. Making avail of this favorable condition, I have been able, through the assistance of my colleagues in the survey, to secure a much more accurate section of the Gay Head deposits than has previously been obtained. The section given in the above-mentioned report on the geology of Martha's Vineyard exhibits the beds shown at Gay Head in the form of an ordinary continuous monoclinal. This was the only interpretation which was possible at the time this report was prepared. The section here presented shows that the former interpretation of the attitude of these beds was much in error. They are not in fact generally in monoclinal attitude, but are to a great extent singularly compressed, somewhat collapsed foldings of the strata.

The faint traces of these dislocations which were visible before the rubble was cleared from the Gay Head escarpment by the great rain storm above referred to were thought by me as well as other observers to be due to irregular sliding on the face of the escarpment as the detached masses from the front made their way downward to the sea. The clearer view which has recently been obtained has shown this opinion untenable, for the foldings are now traced back to the portion of the cliff which is so little disturbed by slipping that the beds are seen in approximately their original attitudes. It is now perfectly apparent that while some of the lesser folds may be due to the irregular rate of the journey of the masses downward, the main dislocations are clearly of an orogenic nature.

Long-continued work on the general surface of the bed rocks, the strata below the drift, in other parts of the island has also revealed the fact that these deposits as a whole are not of monoclinal type, but are apparently pervaded by similar great foldings. In the Gay Head district the prevailing strikes of the beds are shown on careful review to be substantially those stated in the preliminary report—that is, the axes of the folds are in a prevailing northwest and southeast direction. There is, however, a considerable variety in the attitude of the foldings, the range of strike being from N. 20° E. to N. 120° E. As will be seen by the diagram in plate 9, the orogenic forces have affected the whole of the section. No portion of the beds apparently retain their original attitude.

In the Chilmark and Tisbury districts, which lie east and northeast of Gay Head, beyond the deep depression occupied by Menemsha and Squibnocket ponds, a sudden change in the strike of the beds is observed. For a distance in a northeasterly direction of about 10 miles the beds have an almost invariable strike of northeast and southwest. Owing to the absence of good sections, the foldings of the strata are not so traceable as in the Gay Head section. There appear to be at least two well-defined folds answering

to the main valleys of the Chilmark and Tisbury district; yet others may be concealed beneath the covering of drift materials. In this connection it is important to remark that the folds of the Gay Head series are not distinctly expressed in the topography, and but for the great section at Gay Head there would be little opportunity to determine their existence. The amount of dislocation in the Chilmark and Tisbury districts probably is nearly if not quite as great as that at Gay Head. The average dip observed at about a dozen points exceeds 45°, and at some points approaches the vertical. The only place where a considerable section is revealed in a clear manner, viz., at the east end of the Nashaquitsa cliffs, the amount of disturbance is as great as in the most dislocated portion of the Gay Head section.

The total area of the dislocated rocks exhibited on Martha's Vineyard exceeds 30 square miles. The most considerable width transverse to the strike is three and one-half miles. The degree of disturbance is about, in a general way, equal in all parts of the section. The only field where the rocks appear to be slightly dislocated lies immediately to the north of the Chilmark pond and includes a surface not exceeding one-half a square mile in area. In this portion of the field the beds, so far as determined by imperfect sections, maintain a nearly horizontal attitude. Taken alone, this relatively undisturbed district might suggest a dying out of the orogenic action in this part of the field, but considered in connection with the fact that the section of Nashaquitsa cliffs indicates as intense disturbances as is found anywhere else in the field, it seems more likely that this unaffected area is a local accident.

Age of the Martha's Vineyard Dislocations.

The section at Gay Head is apparently divisible into two tolerably distinct elements, viz: a lower division, the upper limits of which are not determined, which is likely to prove of Cretaceous age; and an upper part of the section, which from the fact that it contains bones of cetaceans, is likely to prove of Tertiary age—the two together forming the greater part of the longitudinal section of Gay Head. Above these two more ancient portions of the escarpment lie an extended series of unfossiliferous sands, which apparently belong to a somewhat later age than the other portion of the section. To this age we may also presumably assign the extensive series of beds exhibited in the Weyquosque series. These later-formed beds are, at least in the Weyquosque cliffs, deposited unconformably upon the earlier series. A portion of these later unfossiliferous sands are involved in the contortions at Gay Head, and a portion of them lie unconformably upon the edges of the beds which were involved in the dislocation. It seems likely, therefore, that this later series will in the end be found divisible into two parts—a

portion which was laid down before, and a portion formed after, the greater part of the disturbance had been effected.

The geological age of the several members of the Vineyard series must still be regarded as somewhat doubtful. The fossils found in Tisbury, near Indian hill, and described in a bulletin of the Museum of Comparative Zoölogy,* show the presence of distinct Cretaceous beds, probably belonging to the middle or lower member of that series, lying apparently at the base of the deposits found in place on this island. The lower portion of the section at Gay Head is likely also to prove of Cretaceous age. The middle portion of the Gay Head series is presumably of Tertiary age. Although a good many fossils have been obtained from it, there are none of them of sufficient determinative value to establish anything more than the general relations of the deposit. The presence of the cetacean bones and the type of form of the large shark teeth, as well as the general character of the molluscan remains, pretty clearly establish the fact that the beds are above the base of the Eocene and below the summit of the Miocene. On the whole, the aspect of the fossils is most reconcilable with the supposition that the beds are mainly, if not altogether, of Miocene age. The uppermost sands contain no fossils, and their age is therefore undeterminable. Their general aspect is that of rather recent accumulations, and if we consider the middle portion of the section as of Miocene age they may perhaps be referred to the Pliocene section. At any rate, I do not think it probable that they belong to the level of the Upper Miocene.

On the basis of this determination as to the age of the Vineyard rocks, we may seek to determine the time when the dislocations exhibited by this series occurred. It is, in the first place, clear that these disturbances, which folded and faulted the beds, continued down to the time when the newest division of the section exhibited at Gay Head was deposited. If these deposits be of Pliocene age we are compelled to suppose that the orogenic movements were maintained down to that time. The question whether the whole of the dislocation took place at this late age is not so readily determinable. It is evident that after the time when the osseous conglomerate was deposited, which presumably occupies a portion of the Miocene division, the beds were subjected to considerable erosion, which broke up the deposit and delivered pebbles of the materials to later strata. It is possible, however, that this exposure of the osseous conglomerate to erosive action was due not to orogenic dislocation but to the laying bare of the beds while in a horizontal position, in the form of an escarpment, which was attacked by streams or the sea. So far as is yet determinable, we may assume either that the dislocation of the strata occurred in one period in the later Tertiaries or that it may have happened at various times between the depo-

* Op. cit.

sition of the Cretaceous and the formation of the last beds exhibited in the section. There are unconformities observed by my assistant, Mr. Woodworth, apparently indicating a period of tilting coming immediately before the deposition of the upper bowlder bed. It will require, however, more detailed study to determine this point in a satisfactory manner. The relatively slight disturbances of the later sands in the Weyquosque cliffs, if they be orogenic, as it seems to me likely, would indicate a period of disturbances coming after the lower members of the Vineyard series had been subjected to considerable erosion. So, too, the disposition of the later sands in the Gay Head section also indicate in a tolerably satisfactory way the existence of a measure of disturbance after a considerable erosion of this series.

It is as yet impossible to determine the area affected by the dislocatory forces which have operated on Martha's Vineyard. One of the neighboring localities of apparently the same age as the Vineyard series is that long ago made known by Dr. Hitchcock, in his Geology of Massachusetts, as occurring in Marshfield, Mass. With the help of my assistant, Mr. C. P. Sinnott, I have recently made a considerable study of this deposit. Several excavations have shown that the area it occupies covers rather more than a square mile in surface. The whole of the material appears to consist of layers of greensand, in appearance substantially like those which occur at Gay Head. It seems, however, from the fossils obtained that the identity in physical character of the material does not afford legitimate presumption as to their likeness in age. The few molluscan remains obtained appear to be of an earlier time than those occurring in the greensands of Gay Head. They are on the whole reconcilable with the supposition that the Marshfield series is of Cretaceous age, probably belonging somewhere near the middle of the series. It is a noticeable fact that these Marshfield beds appear to retain their original, nearly horizontal, attitudes; although the bedding is not very distinct it is sufficiently clear that it is prevailingly horizontal, and thus shows that orogenic disturbances have not operated in this field since the layers were accumulated.

My assistant, Mr. Aug. F. Foerste, has observed on Block island beds which he considers as probably identical in age with those which are presumed to be Tertiary in the Gay Head series. These deposits of Block island, according to Mr. Foerste's observations, lie at such angles as to make their dislocation by mountain-building forces almost certain. I have not myself had an opportunity of examining these Block island deposits; but, accepting the above-indicated observations of Mr. Foerste, it seems clear that we have a prolongation of the mountain-building disturbances which have affected this shore to the westward as far as that island.

It will be interesting to determine whether these mountain-building disturbances of late Tertiary age had any part in producing the very extensive

foldings of the Carboniferous rocks in the neighboring Narragansett basin. The only evidence on this point is that above cited from the locality at Marshfield. This locality is situated at the northeastern extremity of the great Narragansett synclinorium. The presumably Cretaceous beds at this point are deposited in a great pocket formed by a long-continued land erosion in the granitic rocks which occupy the anticlinal node at the northeastern end of the Narragansett basin. The fact that this anticlinal district has suffered no considerable dislocation is in a certain though insufficient way evidence that the neighboring synclinorium was not disturbed during the period of the Martha's Vineyard dislocations.

It seems to me clear that a very considerable geological time has elapsed since the disturbances of the Vineyard series were brought about. This is shown by two classes of evidence: In the first place, on the north shore of the island we have, as is indicated in the section at Cape Higgon, an extended series of deposits to a great extent composed of unstratified materials worn from the older rocks which lie in nearly horizontal attitudes against the upturned strata of earlier age. The time occupied for the erosion and deposition of these sediments must have been considerable. Next, we note the fact that the surface of the island has a strongly accented topography incised upon the beds of Cretaceous and Tertiary age, which was in good part, at least, developed after the deposition of the last-mentioned horizontal accumulations. The considerable width of the valleys in relation to the remaining uplands clearly indicates that the base-leveling process went on for a long time. Yet further evidence of the same nature is afforded by the insulated character of the Martha's Vineyard elevation. It is clear that a deep valley was formed between this elevation and the shore line of the continent to the northward. It is not likely that any considerable part of this excavation was accomplished during the last ice period, for the reason that the Martha's Vineyard area was very little eroded during the glacial time. These points have in the main been noted in my report on the island of Martha's Vineyard, but their importance is now more evident than before. The evidence in this way obtained appears to indicate that while the last disturbances of an orogenic nature which have affected the Vineyard series are of relatively recent geological time, the period which elapsed since their conclusion and before the coming of the last ice-sheet was really great. Although the evidence cannot be fairly presented in a numerical way, it seems to me, considering the amount of erosion as well as the remaining evidence of depositional work, that the time intervening between the close of the Vineyard movements and the beginning of the later glacial period must have been at least twenty times as long as that which has elapsed since the departure of the ice from this field.

In the before-mentioned report on the geology of Martha's Vineyard I have

adverted to the fact that the dislocations at Gay Head have led to the development of axes of elevation having at that point a prevailing northwest and southeast direction. It should be made clear that later studies on the island have shown that this axial direction is not maintained throughout the area of the island. The greater part of the beds in the towns of Chilmark and Tisbury exhibit a northeast and southwest trend. It thus appears likely that the dislocations of this time present a considerable variety in the axial direction of the folds, a portion of them departing widely from the prevailing strikes of the eastern portion of North America, while the larger part conform to that general axis.

Glacial Origin of Bowlder Beds Containing Fragments of the Osseous Conglomerate.

Among the more important results obtained in the later studies on the Gay Head section is one which in a measure serves to affirm the glacial origin of this deposit. In my memoir on the Geology of Martha's Vineyard in the 7th Annual Report of the Director of the U. S. Geological Survey, I have called attention to the fact that a portion of the beds exhibited in the Gay Head series are presumably of glacial origin, formed during an ice epoch occurring in Tertiary time. This evidence was clearest in the case of the conglomeratic beds which abound in certain portions of this section. The facts in hand at the time when the above-mentioned report was published were not sufficient to affirm this hypothesis. During the last summer my assistant, Mr. J. B. Woodworth, was so fortunate as to discover in the conglomerate exhibited just south of the depression known as the Devil's den a fragment of ilmenitic rock which certainly was derived from Iron hill, near Cumberland, Rhode Island. The character of this material is such as to make its origin quite unmistakable. The dense, fine-grained magnetic oxide contains a large number of feldspathic crystals, giving the rock a very characteristic expression.

During the last glacial epoch a bowlder trail was formed from Iron hill down the valley in which lies Narragansett bay and thence eastward to the peninsula of Gay Head, whereon the fragments of the material are thinly distributed. This fragment imbedded in the Gay Head section was discovered at a point indicated in the section. There seems to be but little doubt that it was actually imbedded in the mass of the conglomeratic material. Although found on the basset edge of the deposit there was no distinct coating of glacial drift above it, and it has the superficial color proper to the deposit in which it is supposed to have belonged. Moreover, the surface of the fragment is deeply pitted by decay in a manner exhibited by none of the many thousand other fragments which were found in the trail formed

during the last ice epoch. It therefore does not seem to me possible that the pebble could have been driven down into the superficial portion of the old conglomerate by the recent glacial action. It should furthermore be noted that the ancient conglomerate contains a great number of hypogene bowlders which have the same general lithological character as those which were transported to this region from the Narragansett basin during the last glacial period. On the supposition that this old conglomerate is of either Miocene or Pliocene age it thus becomes more probable than before that it is of glacial origin. The fragment in question is about 8 by 5 by 3 inches, and weighs about ten pounds. Before attacked by decay it was evidently of an angular form, such as usually characterizes the pebbles of this very hard material even where they have been transported for the distance of 50 miles or more. It seems impossible that it could have owed its carriage to water action, and it therefore affords important additional evidence to prove the glacial origin of the deposit in which it occurs.

Assuming that the bowlder beds containing the erratics from the Narragansett basin are of glacial origin, the question manifestly arises whether this deposit can be regarded as equivalent in age to the deposits formed during the first advance of the ice over the central portion of the continent, but which have hitherto not been clearly observed in New England. It is still too soon to decide this question. It may be noted, however, that if we regard the above named deposits at Gay Head as belonging to the last glacial period, we are called on to assume the occurrence of a very great interval between the first and second advances of the ice, for the extensive subaërial topography of Martha's Vineyard was evidently developed after these beds had been deposited and uplifted into their present attitudes.

Detailed Description of Sections.

The accompanying illustration (plate 9) contains three sections: the upper (fig. 1) a diagrammatic and partly ideal section from Vineyard sound southeastward to the valley of Tisbury river near the point known as the upper Fisher pond; the middle (fig. 2), divided into three parts, shows the section of the beds in the Gay Head escarpment so far as they have been interpreted; while the small diagram at the bottom of the plate (fig. 3) affords a theoretical interpretation of a certain puzzling section of the escarpment.

The first section (fig. 1) is intended to indicate the evidence which serves to show that the drainage of this country had been completely developed before the advance of the last glacial sheet. It will be observed that the glacial detritus forms but a thin coating on the lower ridges, and has a thickness of only about 20 feet on the higher. At the point selected the glacial waste forms a much thinner sheet than is usual in this part of the

island. A little to the southwest of the highest point in the section the morainal material probably has a thickness exceeding 100 feet. This section is intended also to show that while the Cretaceous and Tertiary beds (the age of which cannot at this point be determined) lie at a high angle, the average declivity exceeding 45°, there lies against them to the northwest a thick section of beds supposed to be of preglacial or interglacial age which have not been disturbed. These horizontal beds are probably of the same age as those which lie unconformably upon the upturned and eroded strata at Gay Head, where they are shown both in the northern and southern extremities of the section. As is indicated in the section, they are well developed from 800 to 1,200 feet west of the steamboat landing. Similar deposits exist along the northwest face of the island from Chappaquonsett pond westward. They probably also occur at the base of the cliffs at Cottage City, and also in the easternmost portion of the Nashaquitsa cliffs near Chilmark pond. On the northern shore and also near Chilmark pond these deposits contain occasional waterworn fragments of fossils derived from the Tertiary strata against which they lie.

The Gay Head section (fig. 2) begins near the steamboat wharf on the shore to the northeast of the light, and extends in a general westerly trend for about 1,000 feet; next in a prevailingly southerly course for about 2,500 feet; then it swings in a southeasterly direction, where it terminates at 6,200 feet from the point of beginning. The delineation exhibits the apparent dips at the points of outcrop, and therefore must not be regarded as a cross-section. The object of the delineation is to give as nearly as possible the aspect of the beds in the present condition of their exhibition. Owing to the fact that the strata are evidently very discontinuous, it is not possible to determine their attitudes at any distance from the outcrop. At certain points, as, for instance, at 4,100 feet from the wharf, the beds are delineated in as yet unexplained positions, care being taken to exclude from such delineation strata which had come to their position by slipping down the face of the cliff. At the point indicated as "the Devil's den" there is a deep recess in the face of the cliff. Here the soft clays and sands, standing at a high angle, have yielded readily to erosive agents which have carried the escarpment back more readily than it has elsewhere been worn away by the sea.

A number of thin lignites, apparently having no considerable extension, are omitted. All the other distinctly determined strata are drawn. The blank spaces indicate portions of the escarpment at present so far covered by detritus that the stratigraphy of the underlying beds has not been determined. At only one point has it appeared possible, in the present state of our information, to infer from the existing remnants of the strata the position and character of the folds, viz., at the part of the escarpment between

1,900 and 2,400 feet from the datum point. Other great folds doubtless exist in the section, as is shown by the fact that at 1,300 feet the greensand and associated beds exhibit the series in reversed order. This fold probably returned through the eroded portion of the beds to some point in the covered portion of the escarpment from 500 to 1000 feet to the east. There is another great fold obscurely indicated near the Devil's den, the extension of which is as yet undetermined. Although a number of faults are indicated in the section, there are doubtless others which have escaped observation. In no other way than by a combination of faults with folds can the frequent inversions exhibited in this diagram be explained.

It will be observed that over a good part of this district the glacial drift is not traceable. Its absence is conspicuous between station 4,100 and the end of the section. The drift also exists in the area near the wharf, but it was not delineated because the escarpment was grass-covered and it was difficult to discriminate the glacial from the lower-lying deposits.

Between stations 2,000 and 2,100, at a height of 80 feet above the sea, a small patch of interglacial or preglacial deposits containing abundant fragments of shells of living species was found. As the portion of the deposit which remained did not contain more than 10 or 15 cubic feet of material, it was impossible to determine its exact relation to the remainder of the section. It is possible that the material came into its position by sliding from a more elevated position.

It gives me pleasure to state that I am indebted to several students of Harvard University for assistance in the preparation of this paper. A large part of the detailed work was done by Mr. J. R. Woodworth. The whole of the sections contained in the plate were drawn by him, and the greater part of the recent field work on this escarpment is due to his labor.

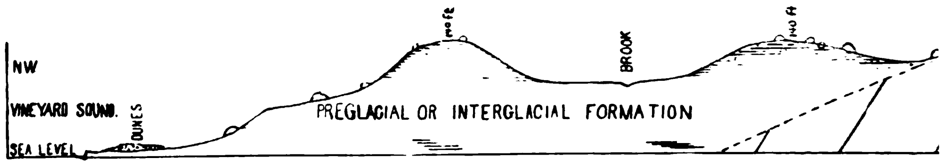
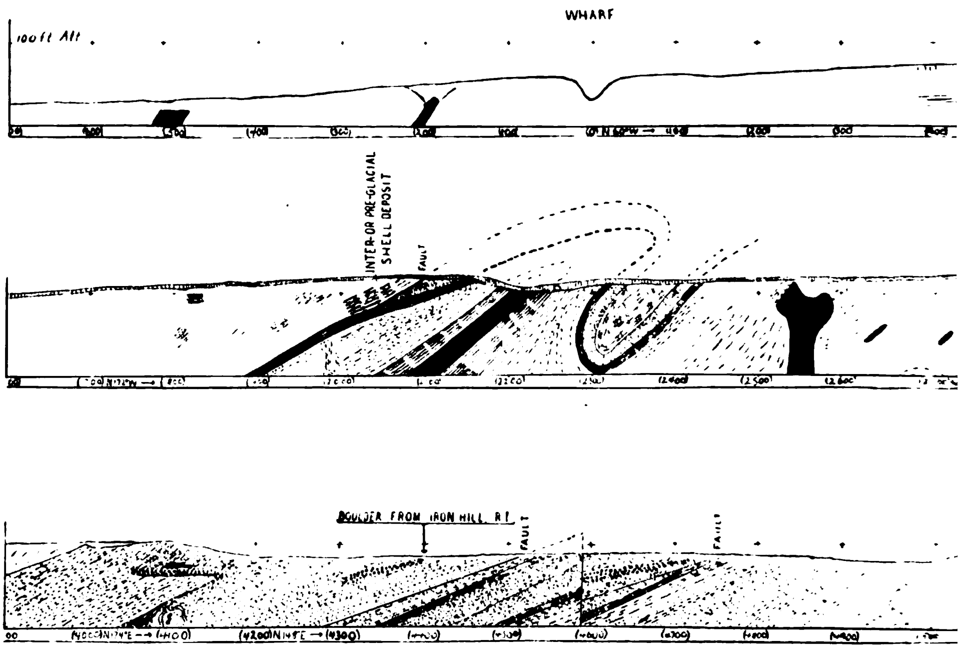


FIG. 1. SECTION 1 MILE LONG, FROM VINEYARD SOUND, (1⅓ Mi. E. of C. Higgon) TO V



RECENT AND LAST GLACIAL

9. *Glacial Drift and Blown Sands*

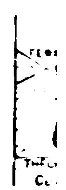
INTERGLACIAL AND PREGLACIAL

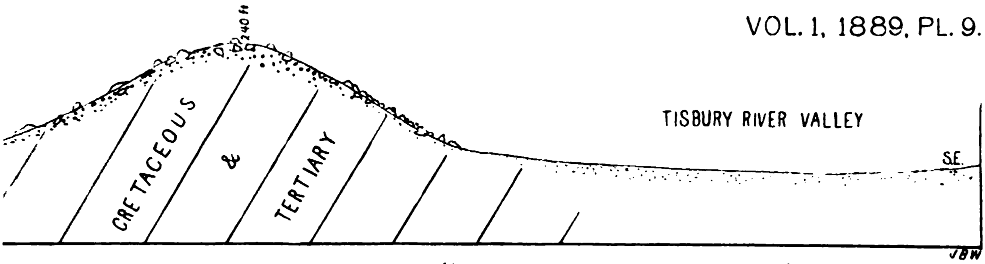
8. *Sands and Clays*
7. *Ferruginous Sands*
6. *Gravel and Boulder Beds*

FIG. 2. VISIBLE SECTION (

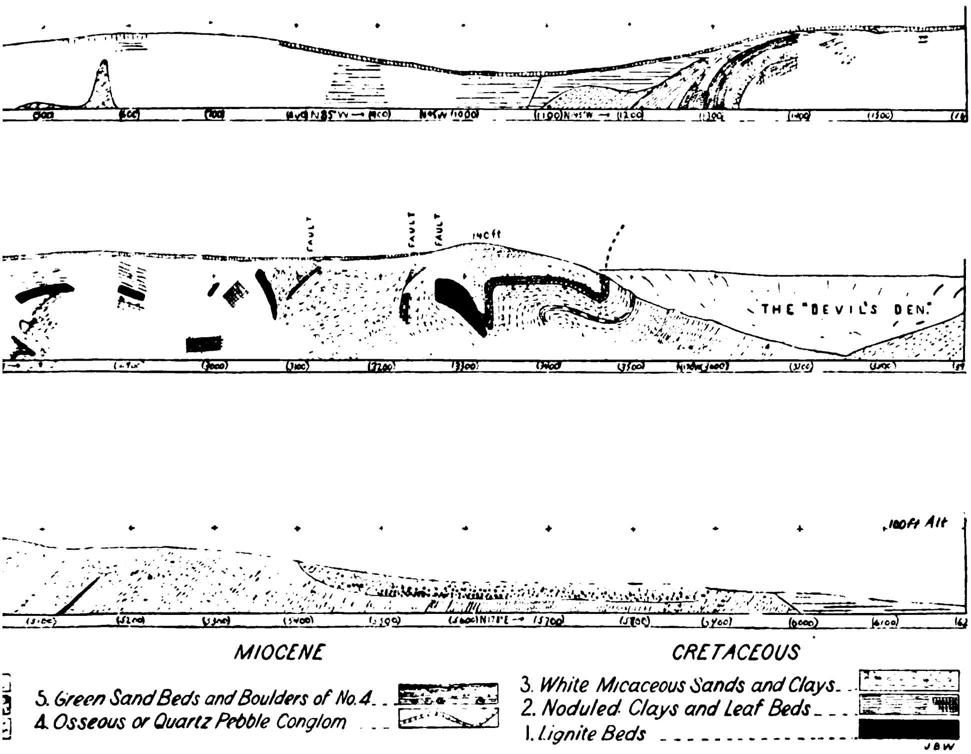
(DISTANC

FIG. 3.



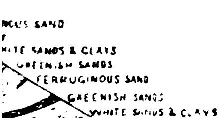


LEY DRAINED BY THE TISBURY RIVER (1½ Mi W. of N. Tisbury P.O.) MARTHA'S VINEYARD.



GAY HEAD CLIFFS IN 1889.

GIVEN IN FEET)



ICAL SECTION PERPENDICULAR TO
ACE AT 4500ft FROM WHARF

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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THE STRATIGRAPHY OF THE "QUEBEC GROUP."

BY R. W. ELLS, LL. D.

(*Read by abstract before the Society December* 28, 1889.)

CONTENTS.

INTRODUCTION.

The discussion of the various opinions which have been put forth from time to time during the last half century as to the age and geological position of the different members of the peculiar series of rocks known among geologists generally by the term "Quebec group," would be an undertaking too great for the limits of an ordinary paper. It is, moreover, to a great extent rendered unnecessary in this place from the fact that the history has already been given with considerable completeness in several publications, among which may be chiefly enumerated papers by Dr. T. Sterry Hunt and Professor Jules Marcou, as well as by the writer, who, in the volume of the Geological Survey of Canada, just issued (1887–'88), has gone into the subject with some detail. This course was deemed advisable, and in fact almost

necessary, owing to the variety of statements, many of which are very conflicting, which have appeared on this subject from a large number of writers; so much so that, even in the case of those who have endeavored to follow out the discussion most closely, much difficulty has been experienced in arriving at a just conclusion as to the real geological position of this group of rocks. When we consider that the bibliography of the subject embraces not less than twenty names and extends over a period of sixty-two years, or from 1827, when a paper by Dr. Bigsby first appeared, it can be readily understood that the task of getting so many diverse opinions together for the sake of comparison is no very easy one.

Historical Review.

Bigsby's View.—It is probably unnecessary to spend much time in the consideration of the earliest views expressed regarding the age and structure of this group. About Quebec and Lévis, where they were first studied by Dr. Bigsby, they were regarded as the probable equivalents of the Carboniferous of England—a view doubtless to some extent arising from the presence of considerable areas of blackish bituminous limestone which occur in that vicinity, and certain curious deposits of black coaly, or rather pitchy, matter found in joints and seams in both the sandstones and shales at various points, the true nature of which was not at that time fully understood.

Bayfield's View.—The next writer on the subject (Admiral Bayfield, 1845) assigned them to a much lower position, and regarded them as the equivalents of the Lower Silurian in their lower strata, passing into the lower portion of the Upper Silurian or Oneida at their summit. This view obtained great favor, and, from 1845 nearly to 1860, the opinion was expressed by all the Canadian geologists that the great area of rocks extending southeastward from the St. Lawrence river and including the mountain ranges of the eastern townships, or central and southeastern Quebec, represented some portion of what was then regarded as Middle Silurian and largely of the Hudson River division of the Champlain group of the New York geologists. Not only did this classification embrace the comparatively unaltered and often fossiliferous sediments of the St. Lawrence basin, but the great series of crystalline schists, gneisses, and associated rocks of the interior as well; these latter being regarded simply as the metamorphic equivalents of the fossiliferous portion, from which all traces of organic life had been removed by the changes to which it was claimed they had been subjected. These altered or crystalline rocks were at the same time regarded as occupying synclinals in the lower or fossiliferous slates.

Logan and Richardson.—The study of the rocks about Lévis and along the south side of the St. Lawrence river in the peninsula of Gaspé revealed

the presence, at many points, of great numbers of fossils, principally graptolites. Large collections were made by Logan, Richardson, and others, which were submitted to Professor James Hall, of Albany, and upon examination were found to be in many respects unlike those from the recognized Utica or Lorraine of New York; but they were at the time regarded as probably representing the Hudson River division of the Champlain group.

Hunt's Studies.—Hitherto the views as to the Hudson River age of many of these rocks were held to be firmly established by the stratigraphical succession of the beds; since there appeared to be a regularly ascending series from the well-defined Trenton on the north side of the St. Lawrence to the summit of the fossiliferous shales of Lévis. Further collections of fossils were, however, made from the rocks opposite Quebec, and in 1856 Dr. T. S. Hunt succeeded in finding in the limestone beds of Lévis the imperfect remains of a trilobite which appeared to be new. Stimulated by this discovery, a vigorous search was at once commenced in the calcareous beds of that place, and many of these were found to be richly fossiliferous—so much so that in a short time nearly 170 species were obtained, not including the graptolites. These were handed for determination to Mr. E. Billings, who found that of this number five were peculiar to the Chazy and twelve to the Calciferous, while yet others had a true Potsdam aspect, and none were observed which indicated a Utica or Hudson River horizon.

This somewhat startling discovery at once overturned the conclusions so long held as to the Hudson River age of the strata at Lévis and vicinity, and led to the reversal of their positions from the top to the base of the Champlain division.

The Founding of the "Quebec Group."—After a careful examination of the evidences obtained by Billings, Sir William Logan, in a letter to Barrande, dated December, 1860, and made public in March, 1861, in the American Journal of Science, expressed the opinion that these rocks represented a great development of strata about the horizon of the Chazy and Calciferous, brought to the surface by an overturned anticlinal fold, with a crack and a great dislocation running along the summit, by which the rocks in question were brought to overlap the Hudson River formation. At the same time he stated that "from the physical structure alone no person would suspect the break that must exist in the vicinity of Quebec, and without the evidence of the fossils every one would be authorized to deny it." To these rocks the name "Quebec group" was now for the first time applied.

With the light thus thrown upon their structure by the determination of the great series of fossils from the Lévis beds, the new "Quebec group" now entered upon an entirely distinct stage of discussion. It was soon divided into two portions, styled the Lévis and the Sillery, of which the former was again subdivided into seventeen parts, representing a total thickness of 5,025

feet, and in which was comprised a considerable variety of sediments. Some of these contained an abundance of fossils, while others were comparatively barren of organic remains. The lowest portion was supposed to consist of greenish shales, mostly calcareous and magnesian, but having interstratified beds of purple color. These graduated upwards into grayish argillaceous shales and limestone conglomerates, with which were closely associated bands of dolomitic limestone and olive-green slates, the latter containing glauconite. In the upper part of the section, beds of gray sandstone and gritty conglomerate occurred together with others largely composed of pebbles of limestone in a gritty or sandy paste. The upper members consisted chiefly of dark gray and green slates with quartzites, which were interstratified with a series of red and green shales, the latter containing fossils, among which were recognized two species of *Lingula* and an *Obolella* presumably *pretiosa*. Some doubt, however, existed as to the true ascending sequence of these several divisions, owing to the fact that of the *Obolella* found in the green slates several allied species were also recognized in the Potsdam formation elsewhere, as well as in what had been regarded as the Calciferous of New York.

Succeeding the red and green shales, which for the time at least were regarded as constituting the upper portion of the Lévis formations, came a series of greenish gray sandstones of peculiar aspect, with shales of various colors—red, green, gray, and black—having an estimated thickness of 2,000 feet. These composed the Sillery division, and were then held to constitute the upper portion of the Quebec group.

In 1864 the Lévis formation was again divided into two parts, of which the upper, comprising a thickness of 3,740 feet, was separated under the head of the Lauzon. This embraced the bulk of the olive-green and red shales with their associated sandstones and quartzites, the sequence in ascending order now being Lévis, Lauzon, and Sillery. In the report of the Geological Survey of Canada for 1866 the Lévis or lower division was said to be distinguished by its generally black or dark color, and was stated to contain nearly all the fossils found in the group, and from the evidence of these fossils the geological position of the base of this division was held to be about the summit of the Calciferous. The middle division, or Lauzon, was marked by a predominance of green and purple shades, the fossils found being only three—the two species of *Lingula* and the *Obolella* already noted—which occurred near its supposed summit. It was, however, further distinguished by the presence of two magnesian bands, one at the base and the other near the top, both characterized in what was regarded as its metamorphic equivalent by the presence of metallic ores. The upper, or Sillery, in its unaltered condition consisted of the green sandstones with their associated shales, which in their altered state were supposed to form the series of highly crystalline

schists and epidotic or chloritic rocks of the mountain ranges of the interior, and which, at their highest part, were also supposed to shade upward into more or less perfect gneisses. It was found difficult to draw any sharply defined line between this division and the underlying Lauzon.

Richardson's later Work.—The views as to the structure of the Quebec group just stated remained unchanged till 1868, when Mr. James Richardson, in the course of his explorations along the south side of the St. Lawrence, upon the evidence of certain fossils there found, advanced the theory that a portion of what had been regarded as Sillery and Lauzon was in reality of Potsdam age and divisible into three parts—lower, middle, and upper. The rocks to which his conclusions more particularly applied embraced certain extensive areas of hard quartzose sandstone, with associated beds of limestone conglomerate, together with slates of various colors. These he considered to underlie the Lévis formation, which was, however, still regarded as being older than the Sillery as first established. The reasons for this change of view were principally the finding of fossils of Primordial age in some of the conglomerate bands, and the presence of supposed *Scolithus* burrows in certain of the quartzose sandstones, many of which in their character were supposed to resemble those of Potsdam age west of Montreal.

This view was not very strongly supported by Sir William Logan, who, upon examination of the evidence, failed to find anything which could conclusively establish their Potsdam horizon; and subsequently the subject was discussed by Dr. Selwyn, who also failed to find any sufficient reason for the separation of the so-called Potsdam portion from the original Sillery sandstone.

Hunt's later View.—In the meantime Dr. Hunt, in 1871, had propounded new views as to the structure of the group, more particularly relating to the supposed altered portion of the interior, in which he claimed that these metamorphic rocks were not the equivalents of the fossiliferous Quebec group, but belonged to an entirely distinct system, and that they should be regarded as older than the Cambrian as then constituted or as a portion of the Huronian, thus completely overturning the views so long maintained as to their equivalency with the Sillery and Lauzon divisions.

Selwyn's Classification.—The study of these rocks was taken up at a later date by Dr. Selwyn, then director of the Geological Survey of Canada, who in 1877 first officially published the opinion that the original Quebec group was divisible into three great systems, viz: (1) An upper portion, styled the Lower Silurian, which comprised the Lévis and Sillery (the name Lauzon having been dropped) unaltered and in places fossiliferous rocks; (2) A volcanic group, probably lower Cambrian, which included quartzose sandstones, red, green, and grayish siliceous slates, serpentines and diorites with dolomites; and (3) a group composed of slaty and schistose, chloritic, mica-

ceous and other rocks, with gneisses and crystalline limestone, the whole somewhat closely related to the preceding but regarded as forming an underlying series of probably Huronian age. These constituted the metamorphic ridges of the Sutton mountain range and its extension northeastward to and beyond the Chaudière river. The views thus presented by Dr. Selwyn were stated, with some slight modification, in several subsequent papers.

The Gaspé Studies.—In 1882 the survey of the Gaspé peninsula showed clearly the presence of an underlying series of crystalline schists, hornblendic and chloritic, with epidotic and other rocks, which formed a large part of the Shick-shock mountains and which evidently represented the eastward prolongation of those just described. These were flanked on the south side for the greater part of their extent by Silurian strata, but on the north, between the mountain range and the St. Lawrence, a considerable thickness of green and dark gray slates, in places schistose, occurred; while the area between these and the river was occupied by the red and green slates, with the sandstones and occasional conglomerates of the original Sillery and Lauzon divisions. These rocks extend continuously from Lévis to Cape Rosier, near the eastern extremity of the Gaspé peninsula, and are exceedingly uniform in character throughout. At very rare intervals an overlying outcrop of fossiliferous Lévis shales is found.

Towards the lower part of the St. Lawrence these rocks are underlain by black shales and limestone, often highly bituminous, and in places by a gray sandstone, the whole containing graptolites and other fossils of Hudson River and Trenton-Utica age. Their apparent underlying position is doubtless due to a line of fault, the continuation of that seen on the north side of the island of Orleans and the course of which, in its extension down the river, was described by Sir William Logan in the earlier reports of the survey. From certain peculiarities of structure at that time observed, it was thought that the true position of the Sillery might really be the reverse of what had so long been maintained, and that it should form a lower stratigraphical series than the Levis, though the work necessary to the final establishment of this point was for the time deferred.

Recent Investigations.

Work in the Eastern Townships.—In 1885 the detailed examination of the rocks of the Eastern Townships was begun by the writer. Commencing at Sherbrooke, the work extended on the west to Richmond and on the east to the boundaries of Maine and New Hampshire. The results of the two years survey of this section appeared in the annual volume of the Geological Survey Reports [illegible], accompanied by a map of the southeastern part of

the province of Quebec. In this map many changes in the geology of this area, as compared with the formations indicated on the general map of Canada, 1866, are apparent. It was found that much of what was then regarded as of Upper Silurian age, comprising the great stretch of country lying to the east of the Sherbrooke and Lennoxville belt of crystalline schists, and forming the extension northward of the rocks described some years before by Professor Hitchcock as the Calciferous mica schists and Coös groups, really belonged, in great part, to an older system. This fact was established not only by its unconformable position beneath fossiliferous Silurian rocks, but by the finding at several points of Cambro-Silurian fossils, both in the limestones of the series and in certain interstratified beds of black graphitic slates. The fossils comprised graptolites of Trenton-Utica age, as determined by Professor Charles Lapworth, similar in character to those obtained from the graphitic shales of the south side of the St. Lawrence—recent examinations having disclosed the presence of these in large quantities and in an excellent state of preservation—together with crinoids and other forms, which under the microscope were found to indicate a horizon of the lower Trenton or possibly upper Chazy. The Upper Silurian areas were limited to basins of small extent or closely infolded beds, and were in all cases clearly distinguishable by their characteristic fossils.

The underlying rocks were divisible into at least two portions, of which the lower or crystalline series, composed of schists of various kinds with epidotic, chloritic, and dioritic rocks, occurred as well-defined anticlinals. Of these, in the section from Richmond to Maine, three principal axes were recognized. The first axis, or that near Richmond, was traced and found to be the extension of the Sutton mountain anticlinal, formerly recognized by Dr. Selwyn; the second or middle axis passed through Sherbrooke; and the third constituted the belt of high land along the border of New Hampshire and Maine, the character and probable age of which had been indicated by Professor Hitchcock some years before. In all these the rocks present great similarity in lithological aspect, and are frequently flanked by slates and conglomerates with interstratified beds of hard quartzite or quartzose sandstone, in places having a somewhat schistose structure. In these areas of crystalline rocks the principal deposits of metallic ores are found, and they are now regarded as of pre-Cambrian and probably Huronian age.

The series intermediate between that just described and the rocks of the great Cambro-Silurian eastern and central basins comprises slates, mostly blackish and often wrinkled, but also of green and purple shades and with interstratified beds of hard grayish sandstone which sometimes becomes a bluish-gray quartzite. In places these rocks are unconformable to the underlying schists, and contain masses of conglomerate often of considerable

extent, some of the pebbles in which are derived from the débris of the pre-existing hills in close proximity and just described. Owing, however, to the great folding which these have all undergone, the two series frequently appear to be conformable. They have not as yet been found to contain fossils, but this is doubtless in some measure owing to the fact that but little attention has been devoted to this aspect of the case. They are, however, in all probability the equivalents of those which flank the Green mountains to the south and from which Walcott has obtained his lowest Cambrian fauna. In the area east of the Sherbrooke anticlinal the upper part of the Cambrian is concealed, but on the west side of the Sutton mountain range, towards the plain of the St. Lawrence, this upper portion is displayed in the red and green slates and greenish sandstones which we recognize as the Sillery proper and into which the slaty and quartzose beds of the lower Cambrian appear to graduate.

In connection with the lower Cambrian of this area, large masses of serpentinous rocks are found. These are in many cases associated with diorites and sometimes with granitic masses. Frequently the serpentine appears as knolls surrounded by slates and sandstones. In some places the slates in contact are bluish-gray roofing-slates, as at Melbourne; in others they are reddish or purple, black or gray, as at Coleraine. In Thetford and Broughton the rocks with the serpentine are quartzose sandstones and bluish-gray and black slates, as is also the case in the Chaudière river section. Serpentines are, however, occasionally found with schistose rocks which are regarded as of pre-Cambrian age, so that it would appear that they are not confined to either one of the great geological systems.

Work on the St. Lawrence.—That portion of the Quebec group more immediately bordering on the St. Lawrence possesses, however, special interest from the fact of its containing fossils at many detached points. During the years 1887–'88 much detailed work was done in this section with the object of determining, if possible, the true stratigraphical relations of the several divisions, and of conclusively solving the question of the relative position of the Sillery and Lévis, deferred from 1882. The results of this work have just appeared in the report of the Geological Survey of Canada, 1887–'88, a brief outline of which may serve to make clearer some of the puzzling questions of stratigraphy and paleontology there presented.

Of the three anticlinals described in the southeastern portion of the province, but one, viz., that of the Sutton mountain, is visible in this direction. This extends for many miles with a regular northeasterly course, and, with some breaks, the series of schists and crystalline rocks already described can be traced into Gaspé. As in the section at Sherbrooke, the schistose series is overlain on either side by the black slates and quartzites of the lower

Cambrian ; but in the section south of Lévis these are in turn succeeded by the great series of red and green slates of the Sillery, which, thrown into complicated folds, occupy a surface breadth of some miles between the river and the interior ridge. All the formations here developed have a very uniform strike, following for the most part the trend of the St. Lawrence. In the course of our examinations, many sections were made directly across the measures, the structure in nearly every case proving to be the same and sustaining the views already expressed in regard to the southeastern area.

What we now consider the lowest portion of the unaltered Quebec group, as developed in the vicinity of Quebec and Lévis and for some miles south of the latter place, is seen in a section on the north side of the St. Lawrence, beginning about ten miles above the city of Quebec. From this point, which marks the line of fault bringing into contact the rocks of the Hudson River formation, what appears to be a regularly ascending sequence of beds is observed till we reach Pte. à Pizeau, about two miles above Quebec, in the district of Sillery. This section we have divided into four parts, and may briefly summarize as follows :

Division 1. Consists largely of quartzose sandstone interstratified with black and gray shales, and contains at one point a band of fine conglomerate made up of small pebbles of limestone and quartz in a highly siliceous paste. No fossils have yet been found.

Division 2. Comprises green, black, and gray shales or slates, with occasional bands of hard sandstone. Thin beds of purple-tinted slates occur in the upper portion. Many of the slaty surfaces are covered with worm trails, styled fucoids in the earlier reports of the Geological Survey. These beds are also well seen on the hill in the rear of Cape Rouge village.

Division 3. Comprises mostly reddish and green shales without sandstones, or with the latter in but small quantity.

Division 4. Consists of sandstones largely developed, with partings (often of considerable thickness) of red, gray, green, and black shale. The sandstones are local, the areas thinning out in either direction ; and the green shales, which are associated with the red, contain *Obolella pretiosa*. These are the typical Sillery sandstones described in the Geology of Canada, 1863.

From Pte. à Pizeau the rocks of division 4 apparently strike diagonally across the St. Lawrence and appear on the south side of the river at Point Lévis, where their characteristic red color serves well to indicate them. At Lévis these are succeeded by the rocks of division 5, which consist of blackish green and gray shales with dolomitic limestone and limestone conglomerate. The black shales contain graptolites, and the conglomerates are fossiliferous both in the paste and in the pebbles. These make up the bulk

of what is known as the Lévis formation. It may here be remarked that no rocks of division 5 have yet been recognized on the west or north side of the river.

The red and green shales and greenish sandstones of division 4 are well exposed on the south side of the St. Lawrence from Point Lévis to the Chaudière river, about seven miles distant, and for about seven miles further on above that stream, to the village of St. Nicholas. Here they are terminated by the fault which crosses from above Cape Rouge and brings the Hudson River into view in an apparently underlying position. On the Chaudière they form a continuous section with a large development of the sandstone portion from the mouth to the Grand Trunk railway bridge, in which section several folds doubtless occur. Just below the bridge several sharp crumplings are seen, and in the green shales at the head of the great falls, three-fourths of a mile below, as well as in those directly at the bridge itself, certain bands contain *Lingula* and *Obolella* in abundance. On this stream no other fossils are found till we ascend to the vicinity of St. Bernard and St. Lambert, where an overlying area of blackish and grayish shales contains *Phyllograptus* and other graptolitic forms which indicate a basin of Lévis fossiliferous rocks underlain on either side by the shales of the Sillery.

From Point Lévis the red and green shales are well exposed on the roads leading southeasterly towards St. Henry; but a short distance below the former place they are concealed by the graptolitic shales which constitute the lowest portion of the Lévis formation. A line of section running southeast from the lower ferry at Lévis, which is one mile north of Point Lévis, to the middle Lévis fort, about a mile and a half distant, shows the rocks of this portion arranged in a series of anticlinals, of which at least four are clearly recognizable. Of these the most westerly is seen near the crest of the hill overlooking the river at Lévis, in a cutting on the road which there ascends to the upper town. The structure of this is clearly an overturn. The beds along the face of the cliff between this point and the old Victoria Hotel at Point Lévis show, by the crushed, faulted, and often overturned character of much of the strata, the extension of the anticlinal in this direction. Several of these anticlinals are indicated on the map and in the sections published in the Atlas of 1864 by Sir William Logan, by whom the outcrops of the several bands of limestone conglomerate were carefully traced. The presence of the red shales of the Sillery formation in intimate association with the fossiliferous Lévis beds was also noted, but these were at that time regarded as an integral portion of the fossiliferous series. This is a peculiarity of structure which now needs to be explained, and the correct interpretation of which reveals very clearly the relative positions of the two divisions.

In order to determine this structure more closely, carefully arranged collections of graptolites were made at various points along a line of section extending from the south side of the St. Lawrence about half a mile below the lower Lévis ferry to Fort no. 2. On this section it was found that similar zones occurred at several places: First, at the river itself, in a cutting on the line of the Intercolonial railway; second, at the foot and in the face of the cliff overhanging the road from Lévis to St. Joseph; and, third, at the city hall on the cliff in Lévis. At all these places the dip of the beds is very nearly the same, or southeasterly; but between locations two and three the extension of the overturned anticlinal already described is seen, and shows that the collections from these places are, without doubt, from strata of the same horizon, repeated on either side of the axis, while the structure of the portion between the cliff and the river is really an overturned synclinal.

Tracing the courses of the other anticlinals which cross the line of section to the southeast, these were found in all cases to be clearly indicated by the occurrence of red shales which on following to the southwest become gradually broader and merged into the great area of red and green Sillery rocks of the Point Lévis and St. Henry section, on which line no fossiliferous Lévis anywhere appears. From the line of the Lévis section northeastward the Lévis rocks gradually acquire a greater extent as we approach the town of St. Joseph, though the anticlinal structure is still clearly visible. It finally appears, therefore, that the Lévis formation proper really occupies the synclinal troughs or folds in the Sillery. These have a manifest dip to the southeast, while to the southwest the Lévis formation has been entirely removed. In the extreme southeast of the section, the Levis graptolitic shales with their bands of fossiliferous conglomerate appear, at first sight, to underlie directly the great mass of the red and green Sillery shales and sandstones of the St. Henry section, and such was evidently the view held in 1866; but on examination of the trenches about the forts, constructed since that date, this apparent superposition of the latter was clearly found to be due to an overturned synclinal in the Lévis beds, the outlines of which could be clearly traced.

Along the coast, both on the south side of the island of Orleans and on the south side of the St. Lawrence, a similar structure doubtless exists, but is complicated by a series of faults. On the island the Lévis formation is confined to a small area at the western extremity and brought into contact with the Sillery shales by a line of fault, while the Sillery itself, often presenting a wonderful series of folded and crumpled strata, occupies the entire south side of the island and the greater part of the south shore of the St. Lawrence for several hundreds of miles eastward from Lévis, or nearly to the extremity of the Gaspé peninsula. Outcrops of strata holding Lévis

graptolites are found at but few points along this coast, among which may be noted a small area near Ste. Anne des Monts, and the extremity of Cape Rosier at the lighthouse, where Lévis forms have been obtained by Dr. Selwyn and Mr. T. C. Weston. These are probably from an included band of Lévis rocks in the Sillery, since the red and green shales and hard sandstones appear a short distance on either side of the point; and it is from this locality that the *Dictyonema sociale* recognized by Professor Lapworth was obtained.

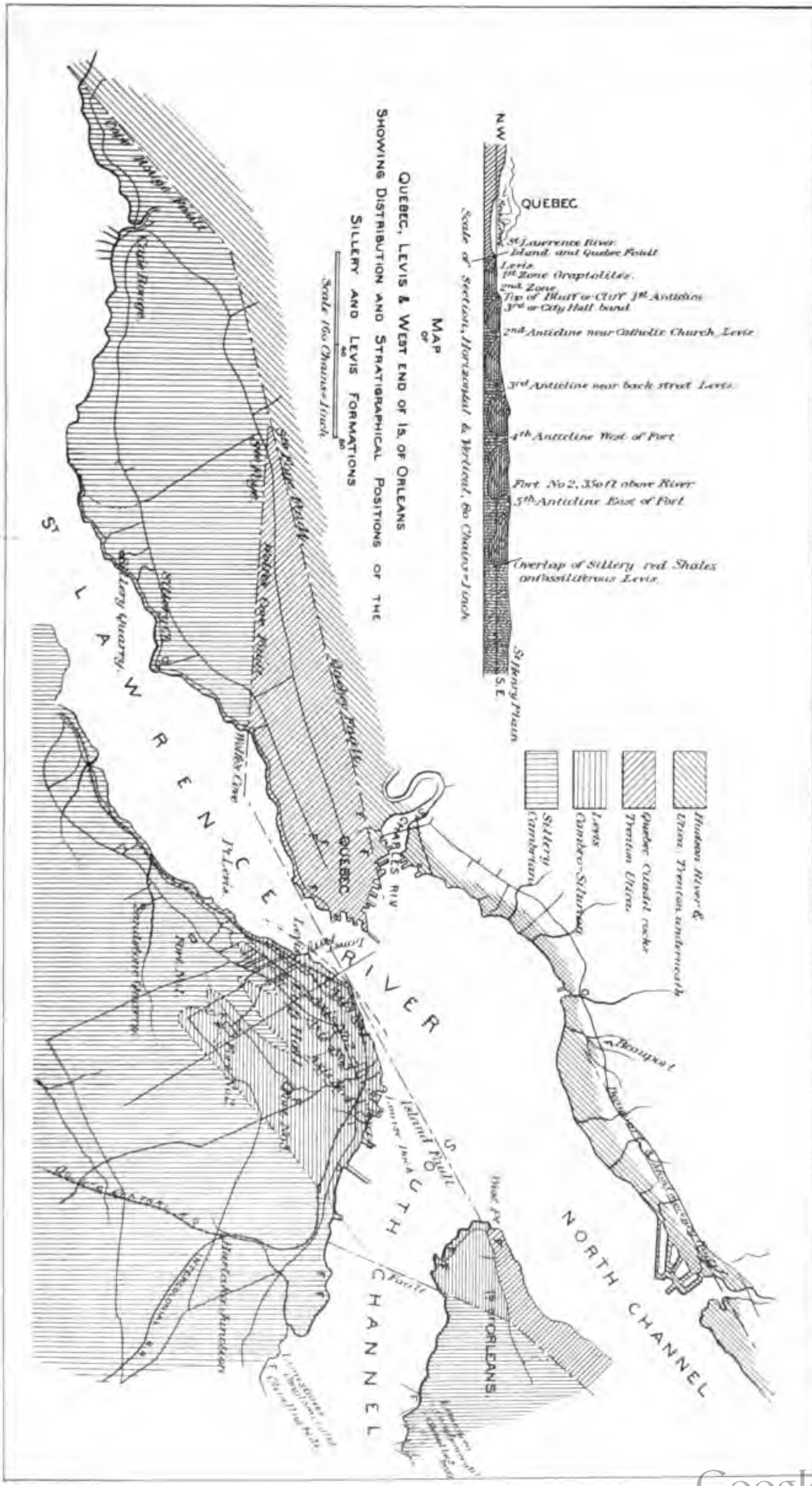
THE SUCCESSION ABOUT LÉVIS AND QUEBEC.

The Stratigraphical Succession.—In the study of the Quebec group about Lévis and along the St. Lawrence much confusion has evidently arisen from the neglect to distinguish the different zones of limestone conglomerate. Of these, several are now known to exist, the horizons or geological position of which are entirely distinct. Areas of conglomerate, not, however, often calcareous, also occur in connection with the slates of the lower Cambrian which flank the ridges of crystalline schist; but these need not here be further described. Of those which occur in the unaltered Quebec group, four well-defined zones are recognized.

The lowest division, which is of but small extent, occurs near the base of the Cape Rouge section and has not yet yielded fossils.

The second zone occurs with the Sillery rocks proper in connection with hard quartzose sandstones or with shales of different colors. They are well seen on the island of Orleans, about two miles east of the hotel at the ferry landing, and on the Beaumont shore or south side of the St. Lawrence, about four miles below Lévis. They also appear at the extreme east end of Orleans island and in several of the group lying in the river between this island and Rivière du Loup, as well as in connection with the quartzites on the main land back from the coast. Further east they are well displayed about Bic and at other points on the north side of the Gaspé peninsula. These conglomerates are frequently coarse, with limestone pebbles, often of large size, which contain fossils of Primordial age, among which *Olenellus thompsoni* is abundant, while the associated shales contain *Obolella* and some obscure graptolites. None of the forms from the Lévis shales have yet been recognized among these, and they are, as a group, distinct from those of the next or Lévis division. In the interior these conglomerates are also seen near St. Sylvester and St. David, south of the Chaudière river, where they are also associated with red and green shales of Sillery aspect.

The third division in ascending order comprises the Lévis conglomerates proper. These are clearly interstratified developments in the fossiliferous shales of that formation, and contain a mixed fauna. Some of the pebbles


MAP OF QUEBEC, LEVIS & WEST END OF IS. OF ORLEANS
SHOWING DISTRIBUTION AND STRATIGRAPHICAL POSITIONS OF THE
SILLERY AND LEVIS FORMATIONS
Scale 160 Chains=1 inch
N.W
QUEBEC
St Lawrence River Island and Quebec Fault
Levis 1st Zone Graptolites
2nd Zone Top of Bluff or Cliff 1st Anticline
3rd or City Hall band
2nd Anticline near Catholic Church Levis
3rd Anticline near back street Levis
4th Anticline West of Fort
Fort No 2, 350 ft above River
5th Anticline East of Fort
Overlap of Sillery red Shales on fossiliferous Levis
Sillery Plain
S.E.
Scale of Section, Horizontal & Vertical, 80 Chains=1 inch
Hudson River & Utica; Trenton underneath
Quebec Citadel rocks Trenton Utica
Levis Cambro-Silurian
Sillery Cambrian
ST LAWRENCE
RIVER
NORTH CHANNEL
SOUTH CHANNEL
QUEBEC
CHARLES RIV
IS OF ORLEANS
Quebec Fault
Island Fault
Beauport
Sillery Quarry
Wolfe's Cove
Pt Levis

of limestone, which are also often of large size, hold an abundance of Potsdam forms, while others have large orthoceratites. The paste of this conglomerate contains fossils characteristic of the Calciferous formation, and in places it is difficult to distinguish between the matrix and the pebbles themselves. These conglomerates are generally very local in their development, and frequently form lenticular masses, surrounded by the characteristic Lévis shales. Much of the confusion arising from the study of these rocks has been to a large extent due to the neglect in keeping clearly separated the fossils of different horizons—*i. e.*, those obtained from the bowlders and those from the paste.

The fourth zone of conglomerates is that seen in the city of Quebec. These are associated with the blackish bituminous shales and limestone of the Citadel series, which have been found to contain a large fauna, embracing graptolitic and other forms, presumably of Trenton-Utica age. These rocks of Quebec city were formerly regarded as a portion of the "Quebec group" proper, and the necessity for their separation was pointed out first by Dr. Selwyn in 1877–'78. The examination of the fossils from these strata by Professor Lapworth and of more recent collections by Mr. H. M. Ami has confirmed the views then advanced as to their later age, and they may therefore be considered as a somewhat peculiar development of strata intermediate between the fossiliferous Lévis shales and the Hudson River formation.

The Paleontological Succession.—The evidences already presented from the stratigraphical standpoint as to the lower position of the Sillery formation have been largely confirmed by the most recent determinations of the fossils obtained from many points. The examination of these was entrusted to Professor Charles Lapworth, whose conclusions were stated in a paper read before the Royal Society of Canada in 1886. In this paper Professor Lapworth clearly recognizes three zones of graptolites, of which the first is styled the Cape Rosier zone, or zone of *Dictyonema sociale* and *Bryograptus*, and is regarded by him as representing probably a portion of the Cambrian system. The second, or Ste. Anne zone, or that of *Phyllograptus anna*, includes the great bulk of the graptolites from the fossiliferous beds of Lévis and vicinity. He regards this as newer by a well-marked interval than zone 1, and as representing the base of the Ordovician or Cambro-Silurian system. The third, or *Cœnograptus gracilis* zone, includes the rocks of Quebec city, the north side of Orleans island and of the shore of the St. Lawrence below the Marsouin river as well as other points, and is typical of a distinctly higher horizon than the last, or probably that of the Trenton-Utica.

From this evidence it is plain that the fossils of zone 1, already obtained, which include also the *Obolella* and *Lingulæ* already referred to, and are from a part of the red and green shale series of the Sillery, are assignable

to the lowest place, and should be regarded as beneath those of the fossiliferous Lévis formation.

During the summer of 1889 the rocks about Quebec and Lévis were examined with some care by Mr. C. D. Walcott, of Washington. The peculiar faunas from the limestone conglomerates, both from the Sillery portions on the south side of Orleans island and from the Lévis formation at Lévis and St. Joseph, were studied with some minuteness. The purely Cambrian aspect of the fossils from the former was clearly recognized, while in those of the latter the Cambrian forms were found to be entirely confined to the pebbles, the matrix of the rock being comparatively rich in fossils peculiar to the Calciferous formation. The bands from which these mixed faunas were taken were at the very base of the fossiliferous Lévis series and almost directly overlying the red shales of the Sillery which were brought into view along the denuded crest of one of the overturned anticlinals already described, thus again confirming the sequence of strata and the relative positions of the Lévis and Sillery formations determined by the stratigraphy as stated in the preceding pages.

Conclusions.

Briefly stated, then, the "Quebec group," as originally constituted, is held to be divisible into at least five distinct portions, in ascending order as follows:

1. A pre-Cambrian series, comprising the crystalline schists, limestones, gneisses, and the associated dioritic, chloritic, and epidotic rocks which form the axes of the several principal anticlinals.

2. A lower Cambrian series, composed of black, green, gray, and occasionally purple slates, with hard quartzites, at times containing much quartz in the form of veins, as well as through the mass of the rock itself. In its lower part it contains conglomerates holding pebbles derived from the underlying series, and serpentines are an important feature.

3. An upper Cambrian series, composed largely of red and green shales with green and gray sandstones, with which beds of limestone conglomerate sometimes occur, the pebbles of which contain fossils of Primordial age, while the slates hold obscure graptolites, *Lingula* and *Obolella*. These represent what was formerly styled Sillery and Lauzon.

4. An Ordovician or Cambro-Silurian series, composed of black, gray, and greenish shales, with bands of dolomite and areas of limestone conglomerate, from the pebbles of which Potsdam fossils are obtained and from the paste others of Calciferous age, the rocks occupying synclinals in the underlying Sillery division. This is the Lévis proper.

5. The Quebec Citadel series, also Cambro-Silurian, the horizon of which is not yet definitely fixed, though the fossils from it have a distinctly Trenton-Utica aspect and may represent a thickening of the lower portion of the latter formation. These rocks are also seen on the island of Orleans at its northwest extremity and for several miles eastward, as well as at various points on the St. Lawrence. They are separated from divisions three and four by well defined lines of fault.

These are succeeded upward by the fossiliferous Utica and Hudson River or Lorraine shales, which are seen at Montmorency falls, Beauport, and other places in the vicinity of Quebec.

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SOME ADDITIONAL EVIDENCES BEARING ON THE INTERVAL BETWEEN THE GLACIAL EPOCHS.

BY PRESIDENT T. C. CHAMBERLIN.*

(*Read before the Society December* 26, 1889.)

CONTENTS.

Limitation of the Statement.—Evidences bearing upon the interval between the glacial epochs may be drawn from various parts of the glaciated field, and from the various phenomena connected with glaciation. It is not, however, my purpose to make any approach to an exhaustive review of these evidences, or even to touch upon the arguments that may be drawn from all the several sources. I desire simply to bring to your attention certain specific evidences that have an important bearing upon the length of the main interglacial interval, and that lend themselves more readily than others to intellectual estimation. The evidences that are especially additional to previous knowledge are drawn from the lower Mississippi valley; but, in connection with these, I shall briefly refer to evidences drawn from other valleys that fall into marked harmony with them.

The Evidence drawn from the Lower Mississippi.—In the lower Mississippi valley the sub-stratum consists of Tertiary deposits. Upon these there is a thin stratum of gravel and sand, known heretofore quite widely as the Orange Sand, although that term seems to have been applied to different formations. This stratum has been very considerably misunderstood. It does not contain, so far as critical investigation shows, any material that

* The facts relative to the lower Mississippi region are drawn in large measure from the observations of my associate, Professor R. D. Salisbury.

may be regarded as glacial, although I think in some of the earlier reports Archean pebbles were cited as an indication that these gravels were contemporaneous with the glacial deposits of the north. They have been critically examined during the summer by my colleague, Professor Salisbury, and during the entire season's search he has not found a single pebble that is referable to a glacial origin. Some years since I examined the same formation with the like result. Professor Call has also examined some of these deposits with a similar result. The pebbles are chiefly of chert, and were derived from the chert-bearing limestones, which are largely Carboniferous, but reach as far down as the Lower Magnesian limestone. They are, therefore, non-glacial. This is a matter of some importance, as these sands and gravels have not only been correlated with the glacial deposits, but referred to the Champlain epoch. They are very far rėmoved from the Champlain deposits in time, and that correlation is one of the great errors of Quaternary geology. They are certainly preglacial in the sense that they were not contemporaneous with the glacial incursion at its earliest maximum. They may have been contemporaneous with the very earliest stages of glaciation before the ice reached the Mississippi valley and was able to mingle its deposits with those of the valley.

Now these gravels occupy a wide area stretching across the basin of the lower Mississippi from some distance back in Tennessee, Kentucky, and Mississippi to the high lands upon the Arkansas side, appearing in the isolated upland called Crowley's ridge, which bisects the present bottom of the Mississippi. The gravel stratum undoubtedly was originally horizontal, but it now undulates more or less conformably with the surface. The explanation of this, it seems to me, is found in the gradual creep of the soft material of the hills as they were slowly carved out by erosion. The brows of the hills in some cases have obviously crept down the slopes, for on the summits we find the gravels compact and firm and the constituent pebbles lying with their maximum diameters in a horizonal position, while the stratum has level upper and lower bounding planes. On the slopes of the hills, however, the gravel beds are more or less broken up and the pebbles have been disturbed and displaced and tumbled into various attitudes, such as we might naturally expect under the hypotheses of a creeping movement on the slope. It seems impossible to suppose that this stratum of gravel was originally deposited in the undulatory form in which it is now found. It might be supposed that the silt which overlies this gravel bed was deposited as a mantle over an undulatory surface, but gravel does not lend itself to such a method of distribution.

The overlying mantle, which now claims attention, consists of fine silt and embraces the loess deposits of the lower Mississippi. It spreads out broadly over the gravel stratum and extends somewhat beyond it, especially on the

east. This stratum is in places differentiated into two parts, separated by a soil-like horizon. This differentiation is not common to the entire valley. The silt mantle may be traced almost in unbroken continuity northward to the border of the glacial drift, whence it spreads itself over the drift, reaching over the drift surface some hundreds of miles to the northward. In this northern stretch the silt mantle is correlated with a second episode of the earlier glacial epoch. It graduates down into a stratum of bowlder clay that overlies a bed of vegetable material, which in turn overlies another till. Both of these tills I have been accustomed to correlate with the earlier glacial epoch. I do not wish, however, to raise differences of opinion on that point here. It is unimportant to the main conclusions which we desire to reach.

Besides this continuity, there is a further reason for regarding these silt deposits as contemporaneous with the ice invasions.

They are made up in part of glacial particles—that is, particles derived from the mechanical abrasion of the glacier. These particles consist of decomposable silicates, dolomites, and limestones and were rasped from rocks of these varities lying further north. Such decomposable particles do not abound in residuary clays but are abundant constituents of glacial clays.

It seems necessary to suppose that this mantle of loess and loess-like silt was originally deposited as a horizontal stratum across the entire Mississippi bottom and border land. At the present time it undulates over the hills. At first thought it would seem that the depositing waters might have been deep and the silt laid down as an undulatory mantle, but it would seem necessary to extend the same hypothesis to the deposition of the gravels, where its application is manifestly excluded by the nature of the deposit. I feel sure from observation in certain cases that full investigation will show this seeming mantling to be the result of the gradual degradation of the hills accompanied by creep of the pliant and plastic material. This phenomenon of creep has a wide expression, entirely independent of the area under consideration ; but upon that I cannot dwell.

During the first glacial episode, the altitude and slope of the lower Mississippi basin were so low as to permit the deposit of this silt on bluffs which are now 200 feet, more or less, above the present Mississippi bottom. Before the second glacial epoch, according to the division I make, there was an elevation sufficient to permit the erosion of the great trench of the lower Mississippi by the predecessor of the present river. This erosion amounts in round numbers to a trench about three hundred feet in depth and about sixty miles in width. Some of the bluffs that are crowned by these silts are 200 to 250 feet in height; and Professor Call's recent investigations show 80 to 100 feet of silt in the bottom. It is, therefore, I think, safe to say that in round numbers there was an erosion of the magnitude named reaching from Cairo south to the Gulf, with corresponding erosion trenches along the

upper branches during the interval between the two epochs. This great erosion represents the interval between the formation of the silts of the earlier glacial epoch and the filling in of the valley deposits of the later glacial epoch, which now demand our attention. If we go back on the glaciated area to the moraines which mark the limit of the later glacial incursions we find, starting from the outer side of these moraines, valley streams of gravel formed contemporaneously with these ice incursions. Tracing these gravel streams along their courses we find that they run down into and partially fill the channels cut in the interglacial interval. On the upper Mississippi, on the Chippewa, on the Wisconsin, and on other tributary rivers we find gravel trains heading on the outer edge of the outer moraine of the later epoch. Passing down through the interglacial trenches there are found represented in the lower Mississippi valley (as I think we may safely say from recently gathered evidence) equivalent deposits in the bottom of the Mississippi overlain, of course, by the more recent deposits. The work of the earlier glacial epoch in the lower Mississippi I conceive to be the deposit of the loess and loess-like silts; that of the interglacial epoch the erosion of the great trench in which the Mississippi bottoms now lie; and that of the later glacial epoch the partial filling of this trench. The trenching is the measure of the interglacial interval, or at least is a partial measure of it.

The Evidence drawn from the Ohio and Allegheny Rivers.—If we pass to the upper Ohio and Allegheny valleys we find phenomena that fall into close correspondence with the foregoing. There are high shoulders and terraces at various points which bear upon themselves glacial river gravels. One of the most decisive, found in the vicinity of Parkersburg, has been described by Mr. Chance and others. Here an old channel runs back from the present course and, curving around a group of hills, returns, forming an "ox bow." In this old channel, glacial river gravels are found, showing that it was occupied contemporaneously with some stage of the glacial period. This abandoned channel is about two hundred feet above the present Allegheny river. Mr. Chance tells us there is about fifty feet of drift in the present valley bottom; so between this upper river bed and the bottom of the present rock bed there is evidence of an erosion of 250 feet, two hundred of which, in round numbers, are cut through Carboniferous strata. Similar and corroborative facts show themselves along the course of the river above and below, and along the Monongahela and the upper Ohio.

If we trace the old channel of the Allegheny northward by means of remnant shoulders and terraces, we find that it lies considerably above the altitude of the terminal moraines of the later epoch, and also much above the gravel trains that head on the outer side of these moraines and run down through the trench above indicated. It therefore becomes a necessary in-

ference that the trench was cut before the moraines were pushed across it, and before the moraine-derived gravels could be carried down into it. The trench therefore represents the interval between the earlier and the later glacial epochs. I have placed in manuscript elsewhere the fuller facts upon which these brief statements rest, and they will appear in print in time.

The Evidence drawn from the Susquehanna.—If we pass over the Susquehanna valley we find like phenomena. These have been brought out by Mr. McGee and others, and I need only refer to them because of their connection with that which I have already presented. Here we find old benches covered with rounded pebbles—some of which are glaciated—reaching to a similar height of about 250 feet above the present Susquehanna river. There are glaciated pebbles at higher altitudes, but I have taken the more moderate figure because it is a safe one. Near Sunbury glaciated stones were found by Professor Salisbury about six hundred feet above the present river. Below these high terraces, and in the valley excavated out of the plain from which they were derived, we find a lower terrace sixty or seventy feet in height, of newer and distinctive aspect. Above Berwick this lower terrace connects itself definitely with the terminal moraine, which there crosses the river. The terrace rises rapidly as it joins this moraine, as is the habit of moraine-headed terraces, and reaches an altitude of 100 to 150 feet as it merges into the moraine. But it is still much below the old terraces, from which it is sharply distinguished by its freshness and other marks of youth and by its constituent material.

It appears therefore that at this point a deep trench was cut in the flood-plain of which the old terraces are the remnants before the formation of the later moraine and of the valley deposits that sprang from it.

The Evidence drawn from the Delaware.—If we cross the Appalachian crest to the Delaware valley we find analogous facts, which are more familiar through the writings of several geologists. Many years ago Professor Lewis called attention to the earlier and later deposits of that region, though he did not give them the interpretation I shall place upon them here, which coincides essentially with that of McGee. As we follow up the valley toward Belvidere, where the moraine crosses the Delaware, we find old terraces reaching up to about 240 by 250 feet, upon which are rounded pebbles and glaciated stones, indicating an origin in the earlier stage of glaciation. Cutting through these old plains and the rock below we find the deep trench in which the later deposits have been placed. These later gravel deposits, originating with the moraine at a height of somewhat above 150 feet, rapidly decline to about 85 feet a few miles above Lewisburg, opposite a point where the older terrace rises to about 250. The measure of the interval here is some 250 to 300 feet of rock-cutting.

Conclusion.—It would appear, therefore, that while there are local variations there is a general correspondence between the amount of erosive work done by the lower Mississippi, by the upper Ohio and Allegheny, by the Susquehanna, and by the Delaware rivers respectively. The facts indicate that the altitude of the continent was low in the closing stages of the earlier glacial epoch; that it became higher in the interglacial interval; and that after sufficient time elapsed for these great erosions to take place, the glacial waters of the later epoch poured their valley deposits down the trenches formed in the interval. The cutting of these trenches rudely measures the length of this interval, or at least the length of the actively erosive part of it.

DISCUSSION.

Mr. W J McGEE: President Chamberlin remarks that the orange sands of the south are largely preglacial or Tertiary. Now "Orange Sand" is the name of a series of deposits grouped and so designated many years ago by Professor E. W. Hilgard. That series really includes deposits of widely diverse ages: Beginning with the newest, it includes certain Pleistocene or glacial gravels forming the basal member of the loess; it includes also the gravels of a wide-spread deposit elsewhere termed the Appomattox formation; it includes, too, certain gravels and loams which are early Cretaceous, or possibly Jurassic—the Potomac formation, or the Tuscaloosa of Smith and Johnson. In addition to these deposits of definitely determined ages, it includes a variety of residuary gravels and loams which extend from the present back to the close of the Jurassic. By far the greater part of the "Orange Sand" consists of materials properly included in the Appomattox formation, and the greater part of the remainder consists of materials which are earlier than Pleistocene. But I desire to call special attention to certain Pleistocene gravels, heretofore classed with the "Orange Sand," which it seems to me that President Chamberlin has overlooked. They occur in parts of the lower Mississippi region, notably in the neighborhood of Vicksburg and Grand Gulf, Mississippi. There may be found a magnificent development of loess, which is charged with fossils and is in all respects so characteristic that these localities may be regarded as typical for the loess of the North American continent. This loess rests on the gravel in question. Now careful examination shows that the loess and gravel are not unconformable, as hitherto supposed, but that the one graduates into the other. This intergradation takes place by interstratification; the loess first becomes sandy at the base, and then becomes interstratified with silts; and still lower the loess appears only in thin layers interbedded with silts, loams, sands, and finally gravels. This stratum of transition may be 10 or 15 feet in thickness; but there is absolutely imperceptible transition by interstrati-

fication from loess above to gravel below. I dwell upon the point because the relation is not the one commonly seen. In the neighborhood of Vicksburg on the banks of the Mississippi, where the bluffs are two hundred feet high, the loess commonly appears to rest unconformably on the gravel. The former is charged with fossils down to a plane of contact as smooth as a floor for hundreds of square yards; and below that plane there is nothing but gravel—stratified and cross-bedded gravel, which President Chamberlin has well described as consisting of chert with no far northern material. But the apparent unconformity has been produced—and the statement is made with hesitation, because it sounds incredible—by movements within the body of the formation since it was laid down; and in some of the better sections in the neighborhood of Vicksburg the character of the movements is illustrated. At one extremity of the best section about Vicksburg (half a mile south of the National Cemetery), the loess and gravel intergraduate as already described; while at the other extremity of the section the usual unconformity appears—the loess resting upon the smooth surface of a gravel bed; but at a point between, a line of fracture cuts off the transitional beds of sand, silt, loam, and fine gravel normally lying between the loess above and the gravel below, indicating either that the stratified beds have been squeezed out, or that the loess has slipped down upon the gravel surface from a higher level. In short, about Vicksburg, there have been landslips of enormous extent, and these landslips have produced the prevailing unconformity. The structure finds expression in a wide-spread but peculiar surface configuration: There are many areas of plane surface one to three miles in extent which remind the geologist at once of fluviatile or littoral terraces; but no two of the planes rise to the same level, and, while all are inclined more or less, no two incline in the same direction or with the same slope; consequently there is a series of unrelated terraces sculptured into hills and ravines yet retaining indications of original attitudes, running over great areas. Thus the whole structure of the Pleistocene deposits in the vicinity of Vicksburg and Grand Gulf, and the whole topography as well, are affected by a series of landslips. The point of present importance is the fact that the loess and gravels together constitute a distinct structural unit. The loess graduates downward into the gravels, and these gravels are Pleistocene; and both represent glacial action, unquestionably during the earlier ice invasion.

President Chamberlin: I think I understand what Mr. McGee refers to. The same phenomena may be seen at Randolph, at Fort Pillow, and on Crowley's ridge. I referred to it hastily, and it is not strange that Mr. McGee should have misunderstood me. At Fort Pillow and at Randolph there are beautiful sections. There are the Tertiaries at the bottom, and then these gravels 8 to 10 feet, more or less, in depth. These graduate, as Mr. McGee has said, up into a silt. This silt ranges up to 8 or 10 or more

feet in depth. The upper part of the silt becomes dirty in color, and at the top there seems to be a clear demarkation from an upper silt. This dark, soil-like band seemed to Professor Salisbury and myself to clearly indicate an ancient surface. Now, that silt, in that region at least, does not contain any of the characteristic fossils—at least they were not found by us; nor, so far as we know, does it show any microscopic peculiarity which indicates its origin. It remains with us an open question whether this belongs to the glacial series or not. Our prepossessions are strongly in the affirmative, because we have two formations at the north for which we wish to find equivalents in that southern region, namely, the lower till, to which I referred in my paper, and the upper till, to which I also referred. We find further north, in connection with each of these tills, loess-like surfaces, and have been searching in the lower Mississippi valley for their equivalents. If we find that the lower silt is glacial, we have what we seek. The interval I described was subsequent to the formation of both these silt series. You are aware that Mr. McGee insists upon there being a long interval between the two silts. I concede that. But it seems to me that the later interval was greater than this. That is simply a point of difference of opinion. The erosion measure I have described is applicable to the later interval. There is no difference between us whatever as to the facts upon this point at least, but there is a difference of interpretation.

Mr. J. R. PROCTER: In addition to the information derived from President Chamberlin's paper, I have come to some knowledge of the facts in regard to the "Orange Sand." My observations in western Kentucky and Mississippi are that the pebbles of that deposit run up into the loess for four or five feet, getting smaller as we rise above the horizon of the Orange Sand. I have found in the Orange Sand at Hickman, Columbus and Paducah silicified fragments of the rocks of the Mississippi valley, as well as Trenton fossils, not very much worn. It is mostly made up of pebbles and chert from the lower Carboniferous, and on the western border we have islands of chert, much worn down, in which the cherty fragments are angular and sharp, and that same chert is found interstratified with the limestones on the eastern border of these recent formations; but as we get nearer to the Mississippi river and further away from the Carboniferous rocks these angular and sharp cherts become more rounded and worn, and I believe that this same Orange Sand deposit is traceable all the way up the Ohio river to the mouth of the Big Sandy, partaking more and more of the character of the northern rock as we go northward. I found the same deposit on Sandy river, but as we get into southern waters of this and other Kentucky streams we find in this gravel deposit (which is in the "second bottoms," or above the high water of the river) no evidences of northern rocks. This is true of the gravels of Kentucky river, the Sandy, and the Licking; but immediately

along the waters of the Ohio, where we find the same gravel, we find the débris of northern rocks at almost the same level. The gravels take the slope of the river, so that we find them at 300 feet above tide at Hickman and reaching up to 700 feet above the sea further up the river; and they are covered all the way, with very slight interruptions, with the silt formation, which may be traced almost to the very head-waters of the stream, partaking of the character of the rocks of the several water-courses. The silt formation is sometimes a loam, and I believe it is traceable all the way down to the loess covering the Orange Sand deposits of the lower Mississippi valley.

Mr. F. J. H. MERRILL: I should like to say a few words in regard to the interglacial deposits of the Delaware. The region south of the moraine near Belvidere has been discussed as a type area. There is a here a broad plain, over 200 feet above the river, which is covered with loam, and underneath which is a certain amount of gravel; this comes up to the margin of the moraine at about 460 feet above tide and about 260 feet above the river. There are evidences of moraines, and there are also small gravel deposits indicating that a body of water stood on the southwestern margin of the moraine, and that this great plain along the Delaware river and valley was filled with a body of water, either a lake or an estuary. I want to ask President Chamberlin how, in a valley which has been filled with water subsequent to the formation of the moraine, we are to distinguish glacial material that might have been deposited in the water that filled the valley from any glacial material that might have been laid down in that valley before the moraine came into existence? There are evidences that this valley of the Delaware at the southwestern margin of the moraine was filled with water to a height of about 460 feet above tide; and I am anxious to know if there is any test by which the later glacial deposit can be differentiated from the earlier one under the conditions I have mentioned.

Professor I. C. WHITE: The facts presented by President Chamberlin from the valley of the Ohio have always been interpreted differently by other geologists who have studied that region. There is everywhere along the valleys of the Monongahela and Ohio evidence of submergence, and the question which has just been asked is very pertinent. How are we to discriminate, or what test shall we employ by which we can recognize the difference between glacial material brought down by the water from these northern moraines and distributed all along the valley and that brought down by the ice? Now, my observations in the Monongahela valley have shown that we have an area extending over hundreds of square miles covered with clays, showing unquestionably that deposits were made in water. These clays mantle the hills where the surface is not too steep and they extend up to about 1,100 feet above the sea. I have during the present summer made a

discovery with reference to these deposits which connects those of the valley of the Ohio with those of the Monongahela valley. Any of you who travel along the Parkersburg branch of the Baltimore and Ohio railway will observe that west of Clarksburg the railway crosses a summit. On one side the water drains into the Ohio, and on the other into the Monongahela. It is a broad, level summit, having an elevation of 1,100 feet, in a gap of probably 300 feet below the enclosing hills. That gap, or valley, is covered by a deposit of fine clay. The cut through it is about 30 feet; and one can observe the succession of clays of all kinds and of different colors, from yellow on the surface down to the finest white potter's clay at the level of the railway where the cut reaches bed-rock, thus proving that the region has been submerged. This submergence would carry a water-level up the Allegheny valley into the region to which President Chamberlin refers, and would satisfactorily explain the phenomena there without recourse to a "second glacial epoch," where the evidence of neither a "first" nor a "second" ever existed.

President CHAMBERLIN: It is the work of the geologist to distinguish between the deposits formed by water running on a slope and those formed by static or horizontal waters. These differences are clear and sharp when the formations are well developed, and are capable of positive discrimination. In respect to the deposits on the Allegheny and Monongahela and upper Ohio, to which reference has been made, I may say that several years ago Mr. Gilbert and myself spent more than twenty days on this especial problem of discrimination, and satisfied ourselves completely that they were formed by running water, as I think Mr. Gilbert will say if an opportunity is afforded. Mr. McGee has made similar observations on the deposits of the upper Delaware and Susquehanna, and so has Professor Salisbury; and I may say the same in reference to my own convictions regarding these rivers. In the case of the Allegheny and the Monongahela, taken together, the facts are sharp and well defined, and I may make that case typical in my answer. These terraces on the Allegheny and Monongahela rivers are not distributed in horizontal lines along the slopes of the valley as if they were formed by the stationary water by means of wave action on the valley side. Such wave action should be nearly uniform throughout the whole length, except as long stretches or coincidence with the direction of the prevailing winds gave greater force. There are certain characteristic inequalities in the cutting of terraces by a body of stationary water, but the laws and the characteristics are well known, having been very beautifully and sharply brought out by those who have investigated the deposits of the western region. On the other hand, the work done by streams is radically different. The stream cuts wherever in its meanderings it strikes with greater force, and leaves such portions as happen to lie in its concave curves. The resulting

terraces are radically different from shore terraces. Again, the terraces of static water must necessarily be horizontal, and must remain so except as crust flexures distort them. Now, in the Monongahela valley, as was said many years ago by Professor Stevenson, the terraces decline from the south towards the north. The terraces on the Allegheny river slope south towards Pittsburgh. Those of the Monongahela slope north towards Pittsburgh. Now, this is just what we should expect in the case of rivers, but not in the case of lakes. Some of these terraces are rocky shelves, as long ago shown by Professor Stevenson and Professor Chance, who have put correct interpretations upon the phenomena. These rocky shelves extend sometimes nearly half a mile back. Below Pittsburgh one is described by Professor Wright, in exemplification of the submergence theory just mentioned. He states that the shelf is cut back half a mile in the rock. Now, imagine the time requisite for the cutting back of half a mile on one side of the river yet practically nothing on the other side! Again, take the case where a valley passes off among the hills and returns, forming an "ox-bow." Here we have phenomena that do not lend themselves at all to the lacustrine hypothesis. And so, again, if you turn to the material it will be found to be of the kind produced by onward-moving water rolling the pebbles over and over again, rather than by a to-and-fro action which slides the pebbles and gives a different form. The discrimination is not as sharp and clear as in the other case, but is still capable of being made. There are other facts lying in the same line.

I am unable to discuss the evidences of the submergence about Belvidere, because I did not see such evidences. Some of the later terraces are made up of well-rounded fresh gravel, without any depth of silt upon it. Now, if these had been submerged, the greater part of the silt would have been on these gravels and the moraine itself. All of these terraces are evidences, it seems to me, of land conditions since the formation of the later glacial deposits.

Professor WHITE: I agree perfectly with President Chamberlin that these benches which slope downward were the result of erosion, but I claim that subsequent to the erosion of these benches all of them were covered with lacustrine deposits. The proof of this is found in the fact that along the Monongahela and its tributaries there is at the summit of this lacustrine level a deposit of clays and bowlders and erosion débris of every description, beginning at 1,100 feet above sea level and extending down to the present flood-plain. Now, on the Baltimore and Ohio railway there is, it seems to me, an absolute proof of this submergence, because the old valley slopes there on the one hand into the Ohio, and on the other into the Monongahela, and yet the the summit has thirty feet of a clay deposit; and on this summit, and on other tributaries of the Monongahela, these clay deposits cease at

altitudes of 1,075 to 1,100 feet, and above that level there is no deposit—there is simply the decomposed shale and rocks in place. Why should these clay deposits cease near that prescribed level if there has been no submergence during the later history of this valley?

Mr. McGee: To correct a possible misapprehension, I beg to say that the point which I raised a few moments since is an altogether subordinate one. In regard to the general subject of President Chamberlin's communication, I am in perfect accord with him; and having gone over very much of the ground he has described, I can testify to the correctness of his statements of fact. And I should like to add that I consider his communication an exceedingly important contribution to the complex subject of Pleistocene history.

With respect to the phenomena about Belvidere, I desire to add a word: I have been on the ground; I am familiar with the face of the country; I have studied the moraine with its overwash terraces, and the more impressive terraces upon which the moraine was pushed, and so I speak with some confidence concerning the phenomena. On the outer side of the moraine lie the early Pleistocene (Columbia) terraces, one of which must be fully two miles in width and four or five in length, constituting the great topographic features of the region. On the other side of the moraine and along its slopes there may be newer terraces, but if so they are so small that they escaped my observation, although I traversed the ground in search of just such phenomena.

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THE CUBOIDES ZONE AND ITS FAUNA; A DISCUSSION OF METHODS OF CORRELATION.

BY HENRY S. WILLIAMS.

(*Read before the Society December* 28, 1889.)

CONTENTS.

INTRODUCTION.

Geologists are well acquainted with the fact that during certain portions of geologic time, through a system, or several systems it may be, the rocks for a considerable region may indicate conspicuous uniformity in their geologic history. Thus, the Appalachian basin, as it is called, extending from New York to Alabama, and several hundred miles in width, presents in all essential features great uniformity in the nature of the deposits, in their order, and in the sequence of the faunas for the large part of the Paleozoic time.

When, however, comparison is made of sections in widely separated regions, as those of Nevada and New York, although the general sequence of faunas is similar, the details of the geologic history, as recorded by the stratigraphic series, are entirely distinct.

In the first case, whatever differences are recorded in different parts of the region, may be directly correlated by the intermediate sections, and each

geologic period over the whole region may be regarded as recording approximately contemporaneous events, and their faunas as living at the same time. In the second case, evidences may be gathered to correlate the two series within broad limits; but when a wide ocean separates the two sections, correlation of the subdivisions of the grand systems of geology is in a high degree hypothetical, and though in text-books and systematic works it may be pardonable, for practical purposes it is of very little value.

But the geologist, and particularly the paleontologist is constantly called upon to compare the geologic history of different continents: and while it has become apparent that each continent must have its own standard scale of geologic units, it is also of great importance to find, if possible, some points in the several standards where precise correlation is practicable.

The following paper is an attempt to establish such a point of contemporaneity in the standard geologic time scales of Europe and America for the upper Paleozoic.

In the preparation of this paper the facts regarding the rocks and faunas of New York are derived from personal examination and from notes and collections made for the United States Geological Survey by Mr. Ira Sayles under my direction. For the facts regarding the foreign Devonian I am indebted, for England, chiefly to the works of Murchison, Phillips, Davidson, Etheridge, Sowerby, T. M. Hall, W. A. E. Ussher, G. F. Whidbourne, and to personal examination of the collections of the last three gentlemen and those in the Jermyn Street and South Kensington Museums, and of the sections of North and South Devonshire; for continental Europe and Asia to the works of Kayser, Barrois, Gosselet, Dewalque, Mourlon, Oehlert, C. F. and F. A. Roemer, Geinitz, Schnur, Grünewaldt, Keyserling,—Murchison, Verneuil and Keyserling,—Tschernechew, Venukoff, von Richthofen; but especially to the writings of Emanuel Kayser, whose critical studies of the Devonian fossils of both Europe and Asia are invaluable.

The Principles of Correlation.

In discussing geologic formations of different regions of the earth, the geologist requires a method of classification of terranes and a system of notation.

The classifications in use are those based (1) upon the mineral constitution or structure of the rocks, (2) on their stratigraphic sequence, and for sedimentary rocks (3) on their fossil contents.

For the normal sedimentary rocks (which alone are discussed in this paper) correlation of two separate terranes has been attempted, first, by comparison of the constitution of the rocks themselves. This method, except for limited areas, is unsatisfactory, other evidence having conclusively shown that

a continuous terrane may vary in its constitution, in the fineness or coarseness of its constituent particles, or in its composition, in the course of a few miles' distance. Second, stratigraphic sequence is a reliable guide in correlation when the individual strata of two corresponding sections are certainly identified. But it is known that two separate sections through corresponding parts of a terrane may vary considerably—gaps in one may be filled by important strata in another, and strata thick in one section may be thin and insignificant in another. The third means of identifying individual strata, as well as general terraues, is by the contained fossils.

Fossils, as well as mineral constitution, present local variations in strata known to be continuous. Geologic correlation at its best is but approximately correct wherever widely extended areas or separate districts are concerned, because the means of correlation are not constant.

Sequence, or order of succession, is the fundamental principle in all geologic classifications of sedimentary deposits, but the two groups of criteria (lithologic strata and organic species) whose succession is studied are of different natures, and their variations are due to different causes.

Each geologic stratum was originally a sedimentary deposit; hence strata vary with the differences in the original conditions of sedimentation and in the source of the sediments deposited. In consequence, geologic time has little or nothing to do with the lithologic character of the strata. A Cambrian sandstone of one region may not differ essentially from a Tertiary sandstone of another region, and the representative of a Cambrian sandstone of one region may be expected to be a limestone in another.

Since, then, the nature of the deposit must depend upon the local condition of the source of materials and upon conditions of sedimentation, therefore close similarity in the nature of sedimentation or in the sequence must necessarily be more or less local, and correlation by this means will be less and less reliable the more distant the two correlated sections are from each other.

Fossil species, on the other hand, are the remains of organisms which once lived, and of living organisms we know that they are more or less dependent upon conditions of environment; that animals or plants are adapted to air, land, fresh water, or salt water; to differences of environment due to differences of temperature, moisture, height, depth, etc. Faunas and floras also differ, other things being equal, coördinate with geographical distribution; and, most prominently of all, differences are seen in the faunas and floras of each successive stage in the geologic history of the whole world.

Successive strata, then, may contain (*a*) the faunas of successive ages, or (*b*) the faunas of varying depths of ocean, or (*c*) the faunas whose geographic distribution has shifted; and correlation by means of fossils is liable to error from confusion of these causes of difference.

Also, the same species may indicate likeness of conditions which, though shifting geographically, may have continued through the time indicated by a considerable oscillation of the conditions of deposition. Two species, or two faunas made up of entirely different species, may indicate only difference of environment, although of precisely contemporaneous period.

But according to our present knowledge, it appears to be positively certain that organisms have changed for the whole world more or less rapidly and completely with the progress of geologic time. This being the case, if we could ascertain the laws of change as expressed in the several orders and genera of organisms we would be able to determine by them the geologic period at which the deposits containing them were made.

If organisms remained constant under all conditions of environment, or if their differences due to changed environment were of a different nature from those coördinate with continued reproduction, we might use them to determine actual contemporaneity of strata; but this is not the fact.

It is a fact that the characters which present a degree of constancy among closely related forms of two widely separate areas are also in like degree constant for a relatively long time geologically. On the other hand, characters which in series of closely allied species are constant for only limited areas, their variations constituting differences between the species of separate regions, are also different for the species of each successive geologic stage.

Hence, in the use of fossils for purposes of correlation, it happens that a knowledge of the habits, history, laws of constancy and of variation of each species and of the genus to which it belongs are essential elements in the problem.

The mere identity of some species in two compared formations, or even identity of genera with closely allied species, is not alone evidence of contemporaneity. And in this respect, no doubt, the application of the term *homotaxy* to such similar formations, as proposed by Huxley, is preferable to *contemporaneity*.

When, however, we consider the fact that all groups of fossils, when studied comparatively and with a view to ascertaining their historical mutations, do present regular modifications of some of their characters coördinate with geologic sequence, the question is raised whether fossils may not present intrinsic evidence of the position they may occupy in the life history of the genus to which they belong. In the belief that this is possible, I have made an exhaustive study of a fauna which, in Germany, France, Belgium, England, Russia, and eastward, is found between typical middle and upper Devonian faunas, and I have compared with it a fauna occurring in New York in what is called the Tully limestone. In the following discussion I shall endeavor to point out the nature of the evidence by which it seems possible to determine relative contemporaneity of strata by means of fossils.

The Cuboides Zone.

For several years I have been seeking some point in the upper Paleozoic series of Europe and America at which precise correlation might be possible.

It is difficult to find an American Devonian species which does not differ as much from its closest European representatives as it does from its nearest allies in the formations below or in the formations above its normal horizon. Therefore, correlation by mere numerical comparison of lists of fossils must be regarded as having a normal error of at least the length of an ordinary geologic age, or etage, as those terms are used by the International Congress of Geologists.

The sharpness of definition of the fauna of our New York Tully limestone at the base of the upper Devonian, when it is not confused with the Hamilton fauna below (as it has frequently been), led me to select it for special study. It is directly comparable with the "*Cuboides Schichten*" of Emanuel Kayser, who has done more than any one else to classify the formations and faunas of the Devonian rocks of Germany.

The name "*Cuboides Schichten*" was applied by Kayser to the calcareous shales and argillaceous and nodular limestones of Aachen (Aix la Chapelle) and of the Rhenish provinces of Prussia, which immediately follow the *Stringocephalus* limestone.* Across the border in Belgium they are called by Gosselet † the *Frasnien* limestone and shales; in the Harz it is the *Iberger* limestone.

For this northern part of Europe the Devonian history of sedimentation was, first, coarser deposits, sands, and, in some cases, conglomerates, with frequent evidence of volcanic disturbance marking the lower Devonian and beginning of the middle Devonian periods, followed by limestones, thick and massive, in the Eifel; in other regions often associated with calcareous shale and argillaceous shale, and in the upper part purer limestone, as at Pelm, reaching great thickness—over a thousand feet—and characterized by the presence of *Stringocephalus burtini*.

This *Stringocephalus* limestone is recognized in the Eifel district, in the northwest Harz, in Nassau and Westphalia, and in southern Belgium and northern France. It is the *Givetien* limestone of Gosselet and Dewalque.

Above the *Stringocephalus* limestones follow impure limestones or calcareous shales (the German *Mergel*), called by C. F. Roemer‡ *Verneuili Schiefer*, and by F. A. Roemer,§ in the northwest Harz, *Iberger Kalk* and *Goslarer Schiefer*—the *Frasnien* of Gosselet and the Belgian and French authors.

* Emanuel Kayser: Das Devon der Gegend von Aachen, Zeitschr. d. Deutschen geologoschen Gesellschaft, Jahrg., 1870, p. 848.
† M. J. Gosselet: Esquisse Géologique du Nord de la France, 1880, fasc. I, p. 95.
‡ C. F. Roemer: Das Rheinische Uebergangsgebirge, 1844.
§ F. A. Roemer: Beiträge zur geologischen Kenntniss des Nordwestlichen Harzgebirges, 1850.

In the Eifelian and similar sections it is the *Cuboides Kalke* and *Mergel* or merely *Cuboides Schichten* of Kayser. These again are followed by shales and sandstones and occasional impure limestone.

In the transition from the purer *Stringocephalus* limestone to the coarser upper Devonian sandstones, the first stage is that of the argillaceous limestone (or *Mergel*), containing the *Cuboides* fauna; second, a fine-grained, often black and occasionally concretionary shale, containing *Goniatites* very generally, and frequently having few fossils and those small, among which is the *Cardiola retrostriata*. Above these are the *Cypridinen* shales and sandstones and occasional limestones with the later Devonian faunas.

The Cuboides Fauna.

The principal fossils of the *Cuboides Schichten*, according to Kayser,* are—

Rhynchonella cuboides, Sowerby.
Spirifer Verneuili, Murchison.
Receptaculites Neptuni, Defrance.

Besides these, as conspicuous fossils in the fauna, Kayser names—

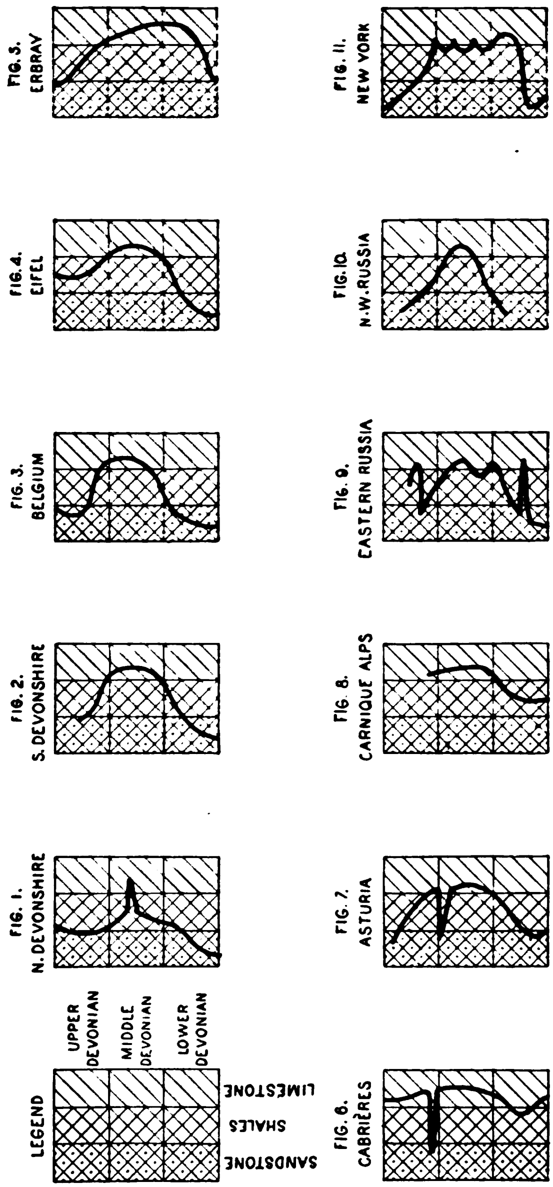
Spirifer euryglossus, Schnur.
Spirifer nudus, Sowerby.
Rhynchonella pugnus, Mart.
Rhynchonella acuminata, Mart.
Productus subaculeatus, Murch.
Athyris concentrica, v. Buch.
Atrypa reticularis, Lin.
Pentamerus galeatus, Dalm.
Orthis eifelensis, de Vern.
Orthis striatula, Schloth.
Melocrinus hieroglyphicus, Goldf.
Phillipsastræa verneuili, Edw. & H.
Acervularia pentagona, Edw. & H.

This precise horizon, with the general sequence from the middle Devonian limestone to the upper or *Condrozien* sandstone, was traced by Kayser from Belgium through these western German sections to the Harz sections, and Poland, Russia, Petschora land, the Urals, Persia, and China.

In each well-exhibited section there is

(1.) The rich middle Devonian fauna: brachiopods, corals, gasteropods, lamellibranchs in abundant variety; trilobites, crinoids, and cephalopods in lesser numbers.

* Das Devon der Gegend von Aachen, l. c., p. 847,


LEGEND
UPPER DEVONIAN
MIDDLE DEVONIAN
LOWER DEVONIAN
LIMESTONE
SHALES
SANDSTONE
FIG. 1. N. DEVONSHIRE
FIG. 2. S. DEVONSHIRE
FIG. 3. BELGIUM
FIG. 4. EIFEL
FIG. 5. ERBRAY
FIG. 6. CABRIÈRES
FIG. 7. ASTURIA
FIG. 8. CARNIQUE ALPS
FIG. 9. EASTERN RUSSIA
FIG. 10. N. W. RUSSIA
FIG. 11. NEW YORK

(2.) The *Cuboides* fauna, with a few species of brachiopods frequent; other brachiopods rare but occasionally present, and only rarely other classes of organisms.

(3.) The *Goniatite* fauna, which is made up mainly of a few species of *Goniatites*, and when distinct, very little else, but frequently blending with the *Cardiola retrostriata* fauna, which is a sparse fauna with a few small *Goniatites*, a few small lamellibranchs, and occasionally *Tentaculites* and kindred forms.

(4.) Following this is the upper Devonian fauna of brachiopods and lamellibranchs, the latter often large and of species distinct from those in the middle Devonian.

With this order of faunas are associated the changes in sedimentation. The first is a calcareous zone formed in an ocean basin not greatly disturbed by shore mud. The second is a deposit of limestone mingled with much clay, showing the waters to have been muddy and impure. The third is a shale, occasionally calcareous, with nodules of limestone, indicating a considerable amount of sediment of attrition, but its fineness of division suggesting considerable distance from its source. The oscillations in the sedimentation of the Devonian system in various places in Europe and America are represented graphically in plate 11.*

We have here evidence of likeness in the general course of sedimentation for all the central part of northern Europe, through the middle and upper part of what is called the Devonian system. For the northwestern part of the Continent and the southwestern part of England, in south Wales and Cornwall, there is evidence of volcanic disturbances in the middle Devonian. The volcanic disturbances, the stage of oscillations in the relation of the land to the level of the sea indicated by the sedimentation, and the fossil contents indicative of the stage of biological progress, all agree in indicating uniformity in the geologic history of this whole region during the period under consideration. It is difficult to conceive any explanation of the facts that does not recognize a comparative contemporaneity for each of the several stages, 1, 2, 3, 4, above named in all its European extent.

When we pass outside of this north European basin, differences in sedimentation are found. In north Devonshire very little limestone appears,

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* EXPLANATION OF PLATE 11.

Each diagram is drawn to a uniform scale. The different rulings indicate different kinds of sedimentation: The right oblique ruling in the vertical columns at the right indicates limestone; the right and left oblique ruling in the middle columns indicates shale or argillaceous deposits; and the right and left oblique ruling with dots in the columns at the left indicates sandstone. The horizontal divisions express geologic divisions of the Devonian system; the lower, middle, and upper divisions standing respectively for the lower, middle, and upper Devonian.

The heavy curved line is drawn to represent the character of the deposits laid down at each stage of the Devonian in the particular area represented by each diagram. For instance, figure 1 represents the sedimentation of north Devonshire: at the bottom the sedimentation curve begins in the sandstone, curves toward the finer deposits, and is in the shales before the close of the lower Devonian; in the middle Devonian it is in the shales with an oscillation into the limestone, and then backward it is formed in the sandy shales during the upper Devonian. In the Erbray section, figure 5, the curve begins in sandstone but rapidly runs over to the limestone. The main part of the lower and all the middle Devonian are limestones.

from the lowest to the highest representatives of the Devonian. Arenaceous shales, schists, slates, and sandstones, with some thin and more or less lenticular limestones, occupy the whole interval. There is, however, a progressive change in the faunas, which is fairly well distinguishable as coördinate with the successive stages in the faunas of the Eifelian Devonian. In France and Spain evidence of the same order of sequence is seen, but the boundaries and divisions are less sharply marked. In Russia similar combinations of species are recognized, but the oscillations expressed by sedimentation are at different stages as gauged by the biologic history. Still, in general, the sequence of faunas is the same. The most that can be said for the representatives of the system further east, in Persia and China, is that the associations of species are closely like those of the several stages of the Devonian in northern Europe.

The Frasnien Fauna of Gosselet.

Gosselet describes the "Calcaire et Schistes de Frasne" in Belgium, giving lists of fossils, in the "Esquisse Géologique," Lille, 1880, pp. 95–97.

The species enumerated by him are—

Bronteus flabellifer.
Cryphæus arachnoides.
Goniatites intumescens.
Spirifer nudus.
" *urii.*
" *euryglosus.*
" *bifidus.*
" *verneuili.*
" *orbellianus.*
Spirigera concentrica.
Atrypa reticularis.
Rhynchonella similævis.
Rhynchonella cuboides.
Camarophoria formosa.
" *megistana.*
Pentamerus brevirostris.
Orthis striatula.
Productus subaculeatus.
Cyathophyllum hexagonum.
Favosites cervicornis.
Alveolites æqualis.
Acervularia goldfussi.
Receptaculites neptuni.

Gosselet notes as a striking fact connected with these Frasnien shales and limestones the inconstancy and irregularity of the calcareous part. Sometimes the limestone is at the base; sometimes in the middle or in the upper part. In one of the sections near Frasne the limestone forms a compact mass 500 to 600 metres thick, in regular beds. East and west it is represented by shales throughout.

All through the northern part of Europe, also in Russia and the Ural mountains, this *Cuboides* fauna is associated with the shaly limestones and calcareous shales terminating the Devonian series of limestones, running up into sandy shales, these latter often black and bituminous, as at Büdesheim and in the *Dominick* schists of Petschora land.

In America the same conditions of sedimentation mark the place of the particular fauna which we correlate with it.

The Tully limestone is always impure, argillaceous, and not only varies in thickness, but changes at its extremes into calcareous shales, and is followed above by a fine, black bituminous shale.

Homotaxy and Contemporaneity.

For all the region so far considered, the evidence is all in favor of the view that in a general way and within comparatively narrow limits the groupings of species into like faunas for the Middle and Upper Devonian period were contemporaneous and not merely homotaxial.

In 1862 Professor Huxley, in the Annual Address of the President of the Geological Society, advanced the view that the correlation of the geologic formations of separate regions by likeness of fossil contents was correlation of order of sequence (homotaxy) and did not imply contemporaneity. He said: "For anything that geology or paleontology is able to show to the contrary, a Devonian fauna or flora in the British Islands may have been contemporaneous with Silurian life in North America or with a Carboniferous fauna and flora in Africa" (Q. J. G. S., Vol. XVIII, p. xlvi.).

Although this is probably nearer the truth than the views then generally held as to uniformity of geologic events for the world, the very methods of research which Professor Huxley has done so much to promote enable us now to predicate much more closely the actual temporal relationship of two separate faunas.

When we consider the area of northern Europe alone, including south Devonshire, and extending eastward to Russia and the Urals and possibly to China, the facts all point to a contemporaneity of the *Cuboides* zone for the whole region.

Assuming this fauna to mark a definite point in the geologic series of Europe, the place of its occurrence in the stratigraphic series may be called the *Cuboides horizon* or *zone*; and the place the fauna occupies in the history of marine faunas, of which it is one, the *Cuboides stage*.

We next raise the question, Is there any evidence of contemporaneity between it and the zone holding the homotaxial fauna in America? The Tully limestone of New York, from both stratigraphic and paleontologic points of view, is homotaxial with the *Cuboides Schichten* of Kayser.

The Tully Limestone and its Fauna.

The Tully limestone is a zone of argillaceous limestone, ranging from a few feet to over fifty feet in thickness, the outcrop of which crosses the middle counties of New York state from Ontario to Chenango counties, but

is not clearly recognized in the sections south of New York. In New York the outcrop is lost to the eastward and to the westward, not so much by thinning out as by a decrease, until unrecognizable, of the calcareous elements, and a failure of the peculiar species. In the central part of its outcrop this limestone appears at the top of the Hamilton formation, which consists of a series several hundred feet thick of soft shales, with a few more or less calcareous zones; and it is followed immediately by a black shale which gradually loses itself by alternate oscillations in a gray, more or less arenaceous shale and argillaceous sandstone, known in New York as the *Genesee shale* and the *Ithaca group*, and the more sandy portion above as the *Portage group*. In the region where the Tully limestone is well developed the black shales contain a fauna corresponding to that of the *Cardiola retrostriata* zone of Europe, and there is in the sandy shales above a fauna rich in *Goniatites* where best developed.

At the western extreme of the Tully limestone outcrop in Ontario county has been seen, far up in the Portage formation, at High Point, a calcareo-silicious zone of about six feet in thickness, containing a rich Brachiopod fauna, which is particularly interesting, as I have previously shown (Am. Jour. Sc. III, Vol. XXV, p. 97, 1883), on account of its relation to a Devonian fauna in Iowa, and to faunas, as we shall see later, in Europe also. The Ithaca zone also contains some of the species of the *Cuboides* zone, as we shall see later.

Above all these comes the typical Chemung fauna of American writers, which is comparable with Gosselet's *Famenien* and *Condrozien* of North France and Belgium.

For this study the more important species in the Tully limestone of New York are the brachiopods. They are—

Orthis tulliensis, Vanuxem.
Streptorhynchus Chemungensis, var. *arctostriata*, Hall.
Strophodonta perplana (var. *tulliensis*, H. S. W.), Conrad.
Chonetes (*logani*, var.) *aurora*, Hall.
Atrypa reticularis, Linn.
Atrypa aspera, Schlotheim.
Rhynchonella venustula, Hall.
Spirifer mucronatus (var. *tulliensis*, H. S. W.), Conrad.
Cyrtina hamiltonensis, Hall.
Spirifer tullius, Hall.
Ambocœlia umbonata, Conrad.
Productella spinulicosta (var. *tulliensis*, H. S. W.), Hall.
Spirifer fimbriatus, Conrad.

Beside these are species belonging to other orders, as follows:

Phacops bufo, Green.
Dalmanites calliteles, or *boothi*, Green.

Bronteus tullius Hall.
Platyceras symmetricum, Hall (var.).

Also representatives of the following genera:

Amplexus,
Aulopora,
Euomphalus (rare),
Pleurotomaria,
Loxonema (rare),
Conocardium (rare),
Schizodus (rare),
Orthoceras,
Goniatites (rare), and
Tentaculites.

Some other genera are represented, but the complete list of genera and species, with descriptions and comparisons, is reserved for a future paper.

What do these Tully forms testify as to their relation to the *Cuboides* fauna of Europe?

The trilobites of the first two genera (named above) are Hamilton species, traces of which are found still higher in the Chemung. The *Bronteus* appears to be unique and is closely allied to a form of the European *Cuboides* zone (*B. flabellifer* Goldf.).

Of the genera of gasteropods, corals, lamellibranchs, and cephalopods, I will only say here that the species are either identical with or closely allied to those of the Hamilton formation below, and the differences at present recognized, on comparing them with their representatives in the preceding zone, are not so great as the differences between the latter and their European representatives of the middle Devonian.

Again, of the brachiopods, the *Atrypas*, are indistinguishable from forms occurring both below and above; hence they are valueless in defining the zone. The *Cyrtina*, the *Ambocœlia*, the *Streptorhynchus*, and the *Spirifer fimbriatus* are seen below and above this zone, and are also represented by closely allied forms in Europe.

The *Chonetes aurora* (figures 10, 11, plate 12) is characteristic of the zone in New York, but the species is not known outside the state. It appears to me clearly distinct from the Burlington *Chonetes logani*, Norwood and Pratten; hence it is of no value in correlating with the Cuboides zone.

Spirifer mucronatus var. *tulliensis* is a well-defined variety, strictly intermediate between *S. mucronatus*, which precedes it, and *S. mesocostalis*, which follows it, in the central part of the region under discussion. It is as perfect an example of a connecting link as one could wish. The *Spirifer tullius* is a forerunner of *S. mesostrialis* of the following Ithaca fauna, and while it

forms a characteristic Tully species in the local sections, it is valueless for purposes of correlation (see figures 12, 13, plate 12).

The *Productella*, varietally considered, appears to be distinctive of the Tully, but it also appears to be local and belongs to a race which is quite sensitive to local conditions all through the Devonian and Carboniferous.

Comparison of New York Species with European Forms.

In the study of all these fossils, no facts have thus far appeared which enable us to affirm other than that the fauna is the regular successor of the preceding Hamilton fauna of the same region. Compared with species of foreign Devonian faunas, these species show less close affinities with them than with their representatives in the Hamilton formation below. At the same time they are nearer to the species of the middle Devonian of foreign sections than to those of any other zone in those sections. They indicate general homotaxial relationship with the faunas of the upper part of the middle Devonian of Europe.

We are now restricted to three species:

Orthis tulliensis,
Strophodonta perplana var. *tulliensis*, and
Rhynchonella venustula.

Orthis tulliensis (figure 16, plate 12) is of a race not represented in the Hamilton of New York. In *O. propinqua* of the Corniferous we recognize its forerunner, and can trace its ancestral line well back into the Silurian. In Iowa, however, this, or a closely allied form, *O iowensis*, is associated with a Hamilton fauna; and in the European Devonian there is a representative of the same race, *O. striatula*, ranging with slight mutations throughout the Devonian system and over the whole region of Europe and Asia. A later mutation of the same race is seen in the common Carboniferious form, *Orthis resupinata*. For the Devonian the differences recognized between the *O. tulliensis* and the *O. impressa* of the following Ithaca zone are no greater than the differences between either one and its representatives in Europe or in Iowa.

Since the race did not appear in the Hamilton of New York, we conclude that *O. tulliensis* came into the region by migration and not by direct descent from any Hamilton form of the same region. Its appearance in the following zone in New York—*i. e.*, the Ithaca formation, and in the High Point fauna in Ontario county—suggests that the fauna to which it belongs is more directly associated with what follows than with the New York Hamilton fauna.

Another point is furnished by the study of this species: *O. tulliensis*, in respect of the variable characters of its race, presents a much greater degree

of constancy than do the forms from Iowa, called *O. iowensis*, or the forms of *O. impressa* from the Ithaca zone.

In the European localities, also, considerable plasticity is seen, especially where the race is abundant. This is interpreted as indicating that the Tully species is a recent arrival in the local fauna.

The second species, *Strophodonta perplana* var. *Tulliensis* (figures 1–4, plate 12), is a mutation of the race which began in *Strophomena alternata* in the Trenton stage. In the Hamilton rocks immediately below the Tully, the form is *Strophodonta perplana*; in the Ithaca zone above, it is *Strophodonta mucronata*, Conrad. This is followed by *Strophodonta perplana* var. *nervosa*, Hall, of the higher Ithaca and Chemung zones.

Without going into details, the prominent points in the geologic mutations are that the race beginning in the Trenton, *Strophomena alternata*, runs through a number of species differing in the proportions of form but retaining the structural features and surface markings with considerable constancy. At the base of the Devonian, two races diverge from the stem; other features remaining alike, the one is a thin, flat, and but slightly curving form, the typical *Strophodonta perplana*, Conrad. This appears to be an American type and is seen with variations all through our Devonian, but it is not described in the European Devonian. The other, beginning flat, in the course of its growth more or less suddenly bends toward the dorsal valve. This is the *Orthis interstrialis*, Phillips, of the European Devonian, and *Strophomena inæquistriata*, Conrad, of the New York Hamilton. The *interstrialis* race is recognized in our Chemung *Strophodonta cayuta* and in the upper and middle Devonian of Europe and the east in *Strophomena dutertrii* and *S. aselli*.

In the European race, as we reach the *Cuboides* zone, the terminations of the hinge develop into slender, mucronate points. In the American race these mucronate points first appear in the Tully limestone forms (figure 1, plate 12), and are characteristic of the race afterward till it ceases.

The representatives of this type of Strophomena are common in Europe throughout the Devonian, going under the specific names *interstrialis*, *aselli*, and *dutertrii*, and the conspicuous development of the mucronate points did not appear till about the stage of the appearance of *Rhynchonella cuboides*. The valuable testimony for correllation furnished by the Tully *Strophomena* is that although plainly, in its main features, an American race of its genus up to the Tully limestone stage, from there upwards it shows affinity with the European representative as it appears in Europe in the *Cuboides* zone and upward.

The third species, *Rhynchonella venustula*, Hall (figures 4, 8, 14, 23, 24, 27, 29, 31–34, plate 13), is by common consent closely allied to *R. cuboides* of Europe, the chief distinction lying in the number of plications in the

median fold and sinus which are less than in the prevailing type of the European *cuboides* (plate 13). Throughout the Devonian of Europe and Asia this species is found associated with a particular fauna at the base of the upper Devonian, and its presence is regarded as indicative of a common geologic horizon; and since it can be traced regularly from country to country, the terranes holding this fauna for the eastern continent may be regarded as approximately contemporaneous.

There is a mutation of the same species, called *procuboides* (figure 13, plate 13) by Kayser, occurring a little lower in some of the sections, the distinctive features of which are seen to be characteristic of immature forms of the true *Rhynchonella cuboides*.

Among the European forms there is considerable variation in the number of plications on the median sinus; some specimens of the American type, however, have as many plications as some of those of the European forms not possessing the maximum number for that type. It is observed, further, that these plications increase in number with the growth of the individual.

This *Rhynchonella venustula* shows a closer affinity to the early mutation of the European form in the characters common to both, but in its own peculiar characters it shows a stage of development akin rather to the typical *cuboides* of Europe. To explain this fact we are led to believe that the two forms had a common origin up to near the beginning of the *Cuboides* stage, but at that stage were separate and developed their local characteristics.

All three species thus agree in bearing intrinsic evidence of a relationship between the faunas of the New York and European Devonian, more intimate during the stages from the *Cuboides* zone upward than for those previous to that zone.

Comparison of European Species with American Forms.

There are beside these a number of species belonging to the *Cuboides* fauna which do not appear in the Tully limestone. Kayser has given a list of species typical of the *Cuboides* zone of Aix la Chapelle and the Eifel section at Büdesheim (p. 485). Gosselet has given lists for the *Frasnien* (p. 488). There are lists given for the *Iberger Kalk*, the Devonian limestone of south Devonshire, and the various sections of Russia and the Urals, by other authors. In the study of these lists the brachiopods also best serve our purposes on account of the much fuller details we possess of their specific and varietal characters and of their distribution. Among the species of these lists the following are quite generally present in the *Cuboides* zone.

Of *Spirifers* there are generally recognized as belonging to the fauna *Spirifer nudus* and *S. euryglosus* or *pachyrynchus*. In the American Devonian the first representative of this race of *Spirifer* occurs above the Tully

limestone, at the base of the Ithaca group. It is *Spirifer lævis* of Hall, which closely resembles Schnur's *S. euryglosus*; the other names are synonyms or closely related species.

Ambocœlia umbonata, Hall, may be said fairly to represent *S. urii*, Fleming, of the *Cuboides* zone. This race with slight variation ranges throughout the Devonian, both in America and Europe, and well into the Carboniferous, and occurs in the Tully fauna as *Ambocœlia umbonata*.

S. bifidus, Roemer, is not represented in the American Devonian. It presents some modifications seen in the later types of our *S. mesocostalis*, but it belongs to a different race.

It may be noted here that the bifurcation of the plications of *Spirifer* and the appearance of plications in the sinus are features continuing from the base of the Devonian to the Carboniferous in Europe. In New York there is a gap from *S. arenosus* of the Oriskany to the *S. disjunctus* of the Devonian, in which no representatives of the race appear. In Iowa *S. whitneyi* and *S. hungerfordi* in a measure fill in the gap.

Spirifer disjunctus, verneuili, orbelianus, archiaci are names applied to varieties of a common race which appears in the *Cuboides* zone of Europe, and also below in the middle Devonian. In the New York sections it first appears in the Ithaca and High Point (Naples) faunas, both of them above the Tully limestone; and again later, as *S. disjunctus*, the most characteristic form of the Chemung fauna. In Iowa *S. whitneyi* occurs associated with middle Devonian species, as in Europe.

Athyris concentrica is generally present in the *Cuboides* zone of Europe, but is apparently wanting in the faunas in America most closely allied. There are representatives of the genus both below and above, but I have not found it in the fauna under consideration.

Pentamerus galeatus, or *brevirostris*, or some other species, is occasionally reported for the *Cuboides* fauna in Europe. With us the species is possibly represented by rare examples, but it is a rare form even in the middle Devonian.

Productus subaculeatus, Murchison, is represented by the *Productella speciosa*, Hall, abundant a little higher than the Tully.

Productus dissimilis, Hall (*hallianus*, Walcott), shown in figures 8, 9, plate 12, is seen in the more eastern sections of Europe. The representatives of this genus akin to the European forms occur after the Tully and not before it

The *Camarophoria formosa*, Schnur, is either a distinct species or is represented by our *Leiorhynchus mesacostalis* of the Ithaca zone.

Orthis striatula, Schloth., and *Orthis eifeliensis*, de Vern., are represented by our *Orthis tulliensis* and followed by *Orthis impressa;* but in New York have no Hamilton forerunners.

Rhynchonella pugnus and *R. acuminata* are frequently reported in middle Devonian faunas of Europe, and in some sections are in the *Cuboides* fauna.

They are particularly characteristic of higher zones, and are abundant in various Carboniferous limestones. With us they begin in New York after the Tully, in the Ithaca and High Point zones (figures 5–7, plate 12); in Iowa they appear in association with middle Devonian faunas, and higher up in the Carboniferous of the western part of the continent.

The form which Kayser described as *Rhynchonella procuboides* (figure 13, plate 13) appeared below the true Cuboides zone in the middle Devonian limestones. It is evidently the forerunner of *Rhynchonella cuboides*, and its occurrence below is quite in consonance with the other facts, showing that the fauna was indigenous to Europe, but that all the representatives of the fauna in New York sections first appeared with or above the Tully limestone.

The *Bronteus flabellifer*, which occasionally appears in the European zone, may be regarded as represented by *Bronteus tullius*, Hall.

Cryphæus arachnoides, reported by Gosselet, is represented in our closely allied form *Dalmanites boothi*, Green, but this as well as the *Phacops rana* are the apparent successors of the indigenous Hamilton species, and this is near their latest, rather than their first, appearance.

The corals and *Receptaculites neptuni*, which are common in the lower zone of the Belgian and Eifel sections, are more local in their character, but most of the corals are generally represented below and not often above.

Thus it will be seen that the European fauna of the *Cuboides* zone is represented almost completely by the fauna which in New York begins with the Tully limestone. Most of the species regarded as characteristic of this zone in Europe there appear also in lower zones, or are represented by closely allied forms that may be safely regarded as their ancestors.

These same species are conspicuous in the New York series by beginning with the Tully limestone and appearing frequently above, but showing no closely allied species in the preceding middle Devonian.

The Transition between the Hamilton and the Tully Faunas.

I have examined a large amount of material from genuine Tully limestone, and also considerable more doubtfully referred to that horizon. In most places the Hamilton rocks are richly fossiliferous immediately under the Tully limestone. These former, though mainly shales, contain limestone beds which in hand specimens are rarely distinguishable from the genuine Tully above; but the characteristic species of the Tully are wanting, and characteristic Hamilton species are abundant in them. Much confusion has thus arisen, and the Tully fauna, as reported in lists,* is very imperfect by

* See list furnished by S. G. Williams in the Report of the State Geologist of New York (Sixth Annual Report of the State Geologist, Albany, 1887, p. 26). A considerable number of the species reported in this list I have examined in the collection made by the author of the list and find them and the rock containing them indistinguishable from specimens obtained at the same locality below the Tully limestone in limestone layers filled with Hamilton species, but never in the Tully limestone itself.

the inclusion of many Hamilton species which do not belong in the limestone.

There are about fifty genuine Tully limestone species. Of these less than twenty-five are at all common, and the other twenty-five are Hamilton species which do not appear above the Tully, or are unique forms of Hamilton types. Of the more or less common Tully forms fully one-half are also clearly Hamilton species or their descendants, or are unique forms.

The change in fauna which begins with the Tully limestone and makes the characteristic upper Devonian fauna includes the appearance in New York of at least ten or a dozen species which have closer affinities with species of the middle Devonian in Europe than with any previous species in the New York series.

The following table will illustrate this point:

European Species.	—	C	+	—	T	+	New York Species.
Rhynchonella cuboides	—	×	?		×	----	*Rhynchonella venustula.*
Spirifer archiaci / " *verneuili* / " *disjunctus*	—	×	—		----	×	*Spirifer disjunctus.*
Spirifer euryglossus or *nudus.*	—	×	—		----	×	*Spirifer lævis.*
Rhynchonella pugnus	—	×	—		----	×	*Rhynchonella pugnus.*
Rhynchonella acuminata	—	×	—		----	×	*Rhynchonella acuminata.*
Productus subaculeatus / *Strophodonta productoides*	—	×	—		×	×	*Productus speciosa* var. *spinulicosta.*
Atrypa reticularis / " *aspera*	—	×	—	—	×	—	*Atrypa reticularis* and var.
Orthis striatula	—	×	—		×	—	*Orthis tulliensis* and var.
Spirifer urii	—	×	—	—	×	—	*Ambocœlia umbonata* or *Spirifer subumbonus.*
Phacops latifrons	—	×	—	—	×		*Phacops bufo.*
Cryphæus arachnoides	—	×		—	×		*Dalmanites calliteles.*
Bronteus flabelifer	—	×		—	×		*Bronteus tullius.*
Platyceras, sp.	—	×		—	×		*Platyceras*, sp.

Of the ten most characteristic species of the *Cuboides* zone of Europe, marked **C** in the above table, all are represented by closely allied forms in the underlying middle Devonian of Europe (— **C**).

Of their New York representatives, six are not known in the underlying middle Devonian (— T); and of the other four, two are species common below and above in both hemispheres, and the other two are more common below in New York as well as in Europe.

Review of the Argument.

To review the arguments: the study of these faunas brings out the following facts. The fauna of the Tully limestone is made up of two groups of species; first, those having closely allied forms in the immediately preceding middle Devonian formations; second, those having closer affinity with European forms than with any species occurring in lower formations in America. The first group may be regarded as representatives of indigenous races and as direct descendants of the lower forms of the same region. The second group must be regarded as immigrants from some other region.

In the Tully limestone the latter class are few, and they are species represented by very closely allied forms in the *Cuboides* zone of Europe, which there were represented by preceding forms which were clearly their ancestors.

In the *Cuboides* zone of Europe are a considerable number of species beside the few seen in the Tully zone. They all have unmistakable forerunners in the formations preceding the *Cuboides* zone in Europe and may be considered as indigenous there. In America all of them follow the Tully limestone zone, generally in the next or in some succeeding brachiopod fauna, or else are first present in the Tully limestone itself.

This series of facts is explained by the hypothesis that during the early stages of the Devonian period there was little or no communication between the basin in which the American species were living and the European basin, but that near the opening of what is called in Europe the *Cuboides* stage, communication was formed, and European species migrated and became mingled with the eastern American forms; that the time of the arrival here of the migrants was while the Tully limestone was being deposited; that the time when the migration left Europe was near the time of deposition of the base of the Cuboides zone; that the correlation thus established is one not merely of homotaxy, but within relatively short limits, of contemporaneity; and that the Tully limestone may be said to have been deposited during the period of deposition of the *Cuboides Schichten* of England, Belgium, France, Germany, Russia, and the East.

Conclusion.

The conclusion we draw from this study of the faunas of the *Cuboides* zone and the Tully limestone is that within very narrow limits, geologically

speaking, the point in the European time scale represented by the beginning of deposition of the *Cuboides Schichten* of Aix la Chapelle and Büdesheim is represented in the New York sections by the Tully limestone; and, second, that the representative of the fauna of the Cuboides zone of Europe is seen in New York not only in the Tully limestone but in the shaly strata for several hundred feet above, including the High Point zone in Ontario county and the Ithaca group in several counties further east.

Therefore, if we wish to express precise correlation in our classification of American rocks, the line between middle and upper Devonian formations should be drawn at the base of the Tully limestone, to correspond with the usage of French, Belgian, German, and Russian geologists, who include the *Frasnien, Cuboides Schichten*, and correlated zones in the upper Devonian.

DISCUSSION.

Mr. C. D. Walcott: Professor Williams' paper is of unusual interest, as he has shown very clearly that the theory of Huxley that there is no homotaxial relation between the subdivision of the geologic systems on the American and European continents is not altogether correct. This study of the *Cuboides* zone has shown one limited horizon, at least, that is widely distributed in Europe which is also readily recognized in the state of New York.

Explanation of Plates.

PLATE 12.

FIGURE 1—*Strophodonta mucronata*, Conrad, var. Tully limestone; Cuyler, N. Y. Ventral valve natural size.

FIGURES 2, 3, 4—The same; enlargement of the surface markings, showing the mode of bifurcation and intercalation of the plications on specimens similar in other respects from a single locality. Figure 2 is enlarged about three diameters, and figures 3 and 4 about ten diameters.

FIGURES 5, 6, 7—*Rhynchonella pugnus*, Martin, var. called *R. alta*, Calvin. Solon, Iowa. Natural size.

FIGURES 8, 9—*Productus hallianus*, Walcott (= *Productus dissimilis*, Hall). Ithaca formation, Ithaca, N. Y. Ventral (8), and dorsal (9), valves, natural size.

FIGURE 10—*Chonetes logani*, var. *aurora*, Hall. Tully limestone. Ordinary size and form.

FIGURE 11—The same. Enlarged nearly four diameters.

FIGURE 12—*Spirifer mucronatus*, Hall, var. *tulliensis*, H. S. W. Tully limestone. Tinker's Falls, N. Y. Exfoliated specimen of dorsal valve representing the common form of the Tully variety.

FIGURE 13—*Spirifer mucronatus*, Hall, var. Hamilton formation. Chenango, N. Y. This specimen represents one of the later Hamilton mutations of the species, and figure 12 represents the stage of mutation intermediate between figure 13 and *Spirifer mesacostalis* of the Ithaca fauna.

FIGURES 14, 15—*Platyceras symmetricum*, Hall, var. Tully limestone; Truxton, N. Y.

FIGURE 16—*Orthis tulliensis*, Vanuxem. Tully limestone; Tinker's Falls, N. Y. Exterior view of dorsal valve of specimen larger than average size.

PLATE 13.

Copies of original figures of Rhynchonella cuboides, *Sow., etc., and drawings of specimens of* R. venustula, *Hall, representing, it is believed, the geographical modifications of the form first noticed under the name* Atrypa cuboides, *Sow.* (1840). *From England, Germany, Russia, China, and North America.*

FIGURES 1, 5—*Atrypa cuboides*, Sowerby; South Devonshire. Trans. Geol. Soc., 2d Ser., Vol. V, Pl. LVI, fig. 24.

FIGURES 2, 20—*Atrypa impleta*, Sowerby; South Devonshire. Trans. Geol. Soc., 2d Ser., Vol. V, Pl. LVII, fig. 2.

FIGURES 7, 13—*Rhynchonella procuboides*, Kayser; Eifel. Zeitschr. d deutsch. geol. gesell., Bd. XXIII, Taf. IX, figs. 3*a*, 3*b*.

FIGURE 6—*Terebratula cuboides* (Sowerby), Phillips; South Devonshire. Figs. and Descr. Palæozoic Fossils, etc., Pl. XXXIV, fig. 150.

FIGURES 3, 9, 15, 30—*Terebratula cuboides* (Sowerby), Geinitz; Saxony. Die Versteinerungen der Grauwacken-formation, Heft. II, Taf. 14, figs. 28, 29.

FIGURES 4, 8, 14, 23, 24, 27, 29, 31, 32, 33, 34—*Rhynchonella venustula*, Hall; Tully limestone, Tinker's Falls, etc., New York. Original drawings.

FIGURES 10, 11, 12, 16, 17, 18, 19, 21, 22, 25, 26—*Rhynchonella cuboides*, Sowerby; according to sundry authors, as follows:

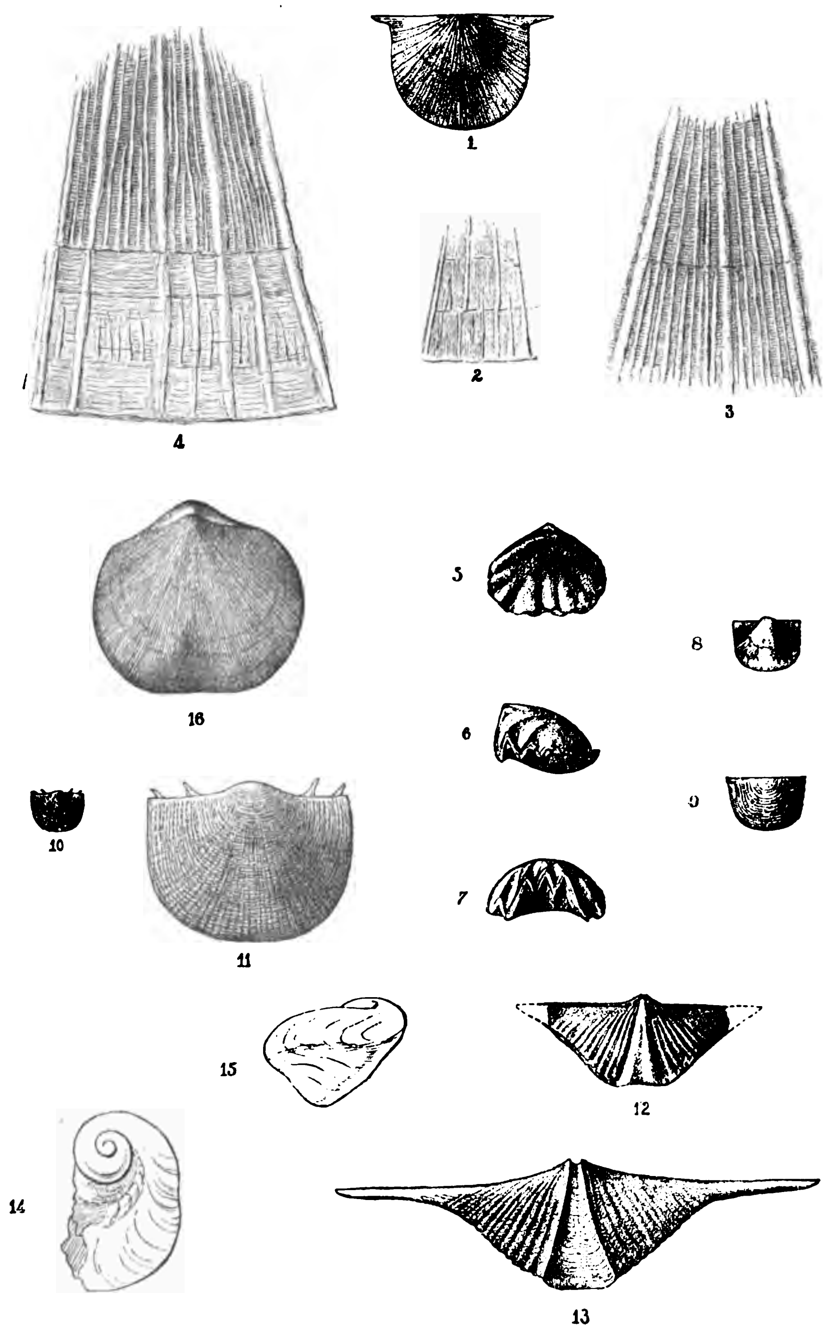
FIGURES 10, 21—Koltuban, } Russia; Tschernyschew. Mem. du Comité gèologique, Vol. 1, No. 3,
FIGURES 11, 16—Dewitza, } Taf. III, figs. 10*a*, 10*b*, 11*a*, 11*b*.

FIGURES 18, 22—Zorin, Russia; Tschernyschew. Mem. du Comité gèologique, Vol. III, No. 3, Taf. XIV, figs. 1*c*, 1*d*.

FIGURES 12, 17—Woronesch, Russia; Wenjukoff. Die Fauna der Devonischen systems im Nordwestlichen und Centralen Russland, 1886, Taf. V, figs. 10*a*, 10*b*.

FIGURES 19, 26—China, Kayser. Von Richthofens' China, Vol. IV, Taf. VIII, figs. 2*c*, 2*d*.

FIGURE 25—Grund, Germany. Original drawing.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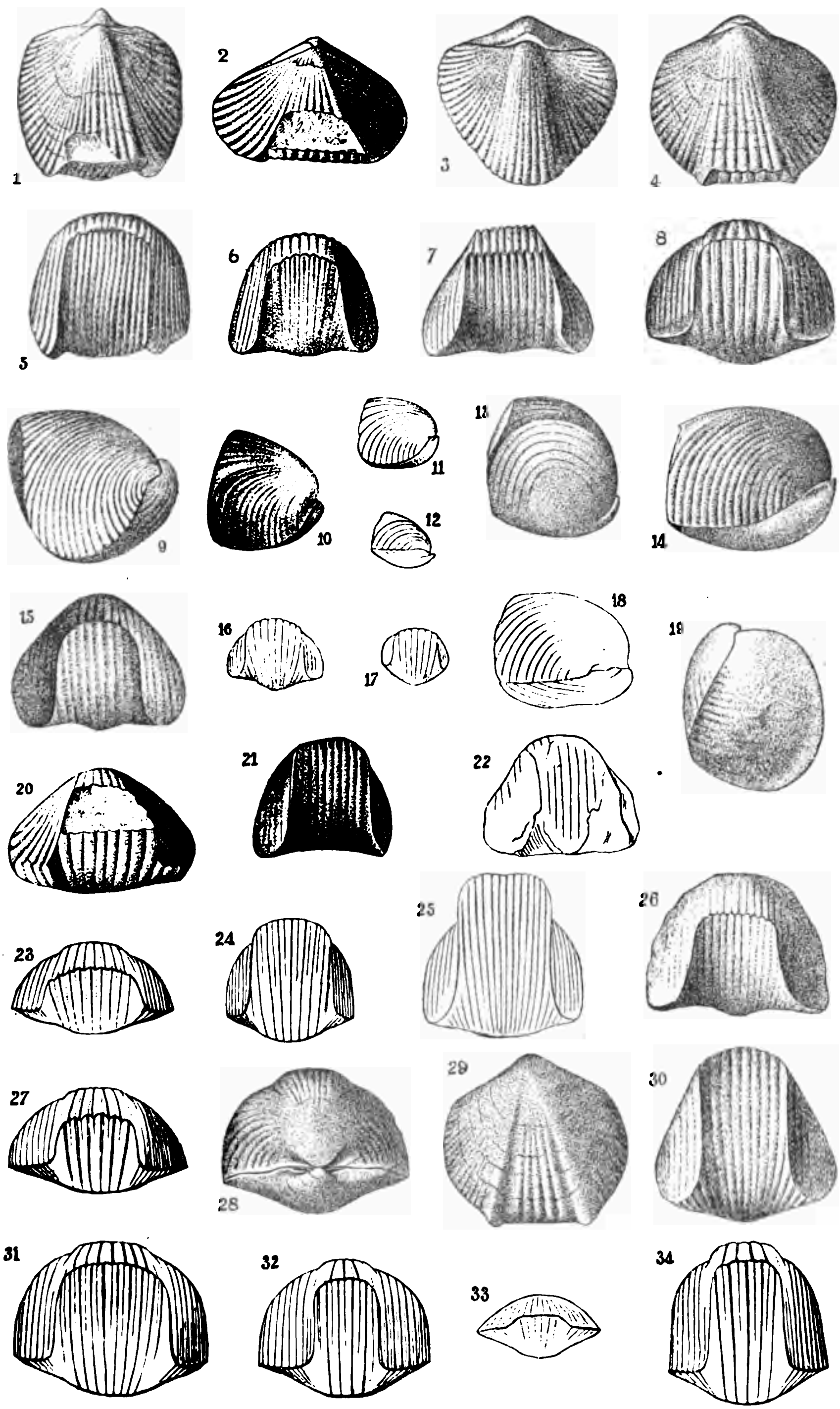
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THE CALCIFEROUS FORMATION IN THE CHAMPLAIN VALLEY.

BY EZRA BRAINARD AND HENRY M. SEELY.

(*Read before the Society December* 27, 1889.)

CONTENTS.

INTRODUCTION.

The region which we have under investigation, lying between the Green mountains on the east and the Archean heights on the west, and extending from Benson, Vermont, and Ticonderoga, New York, on the south, to Philipsburgh, Canada, on the north, has a breadth of about twenty miles and a length of not far from eighty.

Near the western side of this geological cradle lies Lake Champlain, with its islands. On the Vermont side, east of the lake, all the rocks of the Lower Silurian series appear—Potsdam, Calciferous, Chazy, Black River, Trenton, and Utica slate. These rocks sometimes lie in their natural order, forming

great monoclinals where the Archean mass to the west of them has been bodily raised, leaving these dipping principally to the east. Often, however, they appear as though an immense earth wave coming from the east had broken itself along the crest into great fragments, which, displaced and crunched together, are lying in confusion, while another portion of the wave-mass has been shoved up and over, so that the younger rock may be adjacent to or below the older. Near the flank of the Green mountains the disturbances and metamorphism have been so great that the sequence of the rocks is made out with great difficulty.

Our work has been conducted chiefly on the islands and along the eastern border of the lake, and the results of our investigations, so far as they pertain to the Calciferous formation, are here presented.

The Formation in General.

Definition.—The term Calciferous is a convenient one, and is used in the sense in which it was applied by the early New York geologists—*i. e.*, to designate all the strata included between the Potsdam sandstone and the Chazy limestone.

Directly beneath the Calciferous, the Potsdam consists of magnesian limestone and sandstone, the latter containing fragments of brachiopods related to *Lingula*. The overlying Chazy may be separated into three divisions, which, numbering from below, may be designated as *A*, *B*, and *C*. The first, *A*, is characterized by the presence of abundant fossils; its sponges, corals, cystids, orthids, and gasteropods. *B*, the part of the Chazy best known by authors, is characterized by *Maclurea magna*, *Strephochetus*, and a massive *Stromatocerium*. *C* has its dove-colored limestone with bands of magnesian limestone, its many corals, and its *Solenopora*, *Orthoceras*, *Calymene*, *Illænus*, and *Rhynchonella*. Our work with the Chazy, which formation is so largely developed in the Champlain valley, is now well advanced, and we hope soon to be able to present the complete results of our study.

The lines between the Potsdam and Calciferous and between the Calciferous and Chazy are, at this time, only provisional; later investigations must fix the exact boundaries. The lower line is drawn just above the fossiliferous Potsdam; the bottom of the series is a drab magnesian limestone, resting upon a vitreous sandstone; the higher, at the bottom of a sandstone which is assumed to be the base of *A* of the Chazy—a sandstone recognized by the Canadian survey,* which possibly corresponds with the St. Peter sandstone so largely displayed in the central states of the west.

Thickness, Variety, and Faunal Wealth.—In our study of the Calciferous formation we have been surprised at its development, at its vast thickness, at

* Geology of Canada, 1863, p. 123.

its variety of rock, and at its abundant fauna. That the great masters of geological science who made explorations on this ground—Professor Emmons on the New York side of Lake Champlain, and President Hitchcock on the Vermont side—should have made such brief mention of this grand subdivision must be attributed to the fact that they had wide areas to examine and but brief time allotted them. The Calciferous is, moreover, a most difficult formation to decipher because of its great thickness, the absence of fossils in most exposures, and the resemblance to each other of its various beds of magnesian limestone.

The formation is essentially one of magnesian limestone, interstratified with bands and masses of pure limestone, pure silicious sandstone, and mixtures of these; or a calciferous sandstone, from which the name came.

Professor Emmons * gives the thickness as between 250 and 300 feet; but the upper part of his Calciferous has been transferred to the Chazy. President Hitchcock in the Vermont report † assigns it a thickness of 300 feet. But section after section demonstrates a thickness of six times that amount—that is, 1,800 feet. The Vermont report gives the number of fossils as four or five, and in the subsequent pages mentions two more. A collection, not as yet by any means complete, has afforded us over a hundred forms. These fossils can be best enumerated with the various horizons at which they occur.

Principal Divisions.—The formation is not unfrequently marked by abrupt changes in strata; and from lithological and faunal characteristics, a basis may be obtained which may be helpful for study. The divisions may be named *A*, *B*, *C*, *D*, and *E*, reading from below upwards; and in this natural order they will be described.

Division *A* rests upon the uppermost member of the Potsdam. The rock is a dark bluish-gray magnesian limestone, massive or sometimes in beds one or two feet in thickness, more or less silicious, weathering dark, sometimes with a tinge of yellow. Nodules of white quartz are abundant in some of the higher layers, and near the top large masses of black scoriaceous chert make their appearance.

Thus far division *A* has furnished no fossils. It has a thickness of 310 feet.

Division *B* is characterized by the presence of masses of nearly pure reticulated limestone, weathering white, intermingled with light-colored dolomite. The bedding is very obscure. Dolomite prevails in the lower part, and again above the middle; the middle and upper portions being nearly pure limestone. This pure limestone, like the Birdseye in flinty compactness, breaks easily with a conchoidal fracture.

* Geology of New York, 1842, p. 106.
† Geology of Vermont, Vol. I, 1861, p. 270.

The pure rock just above the middle of the division carries the fossil *Orthoceras primogenium*, Vanuxem. It also contains those remarkable hemispherical, banded masses which have been described as concretions, but which are now known to be of organic origin. These masses rest upon a layer of oölite. They were described by Dr. J. H. Steel * in 1825, with a figure illustrating them. Mather, in his report on the first geological district of New York, copied both text and illustration, and in a foot-note added: "Some of the round masses described as concretions analogous to oölites are *organic* and will be described in the paleontological report." † The form found in Shoreham, Vermont, is hemispherical, from six to twenty inches in diameter, banded from the center outward like agate, and with a tinge of purple color. Microscopic sections show the spongy structure of the calciferous sponges, irregular canals penetrating the granular mass. This form may belong to the *Cryptozoön* of Hall; ‡ it is, however, probably different specifically from the Saratoga fossil, and from the earliest known observer it may be appropriately named *Cryptozoön steeli.*

The rock in cliffs looks like a wall of white marble. Reticulations of dolomite appear on the weathered surface. The thickness of division *B* is 295 feet.

Division *C* is sharply separated from *B* below by a peculiar fine-grained sandstone containing some calcareous matter. The weathered portions resemble fine-grained wood, and some layers are pin-holed with worm burrows, *Scolithus minutus*, according to Wing. Upon this sandstone lies magnesian limestone in beds weathering drab, and this is followed by sandstone, sometimes almost like quartzite, but usually calciferous or dolomitic. Above this, and the highest of the division, is a magnesian limestone frequently cherty. The whole division is made up of alternations of sandstone and magnesian limestone.

A few obscure undescribed species of gasteropods and cephalopods are found in division *C*, in addition to the numerous worm burrows at the very bottom. The thickness is 350 feet.

Division *D* may be briefly described as to its lithology. It has at its base blue limestone in beds one or two feet thick, often with magnesian limestone as well as sandy limestone, the latter weathering to a ferruginous granular mass. Drab and brown magnesian limestone follows, which contains also, toward the middle, several beds of tough sandstone. Then comes sandy limestone in thin beds, weathering on the edges in horizontal ridges one or two inches apart, giving the escarpment a peculiar, banded appearance. Blue limestones appear above in thin beds separated from each other by very thin, tough, slaty layers, which protrude on the weathered edges in undulat-

* Am. Jour. Science, 1st Ser., Vol. IX, pp. 16-19.
† Geology of New York, 1842, pp. 411-16.
‡ 36th Annual Report of the New York State Museum, 1883, plate 6.

ing lines. On the weathered surface the limestone often appears to be a conglomerate; in other exposures these conglomerates are replaced by measures of nearly pure limestone, separated from each other by beds of magnesian limestone.

This division, *D*, is particularly fossiliferous, the larger number of fossils in the formation being found here; the purer beds of limestone from bottom to top bearing them. The following 35 genera, gathered from various exposures of the division, are represented by species varying in number from one to ten:

Triplesia	*Murchisonia*	*Nautilus*
Orthis	*Subulites*	*Harpes*
Holopea	*Orthoceras*	*Lingula*
Lophospira	*Lituites*	*Hemipronites*
Bellerophon	*Amphion*	*Clisospira*
Maclurea	*Calathium*	*Rhaphistoma*
Piloceras	*Streptorhynchus*	*Ecculiomphalus*
Asaphus	*Triblidium*	*Ophileta*
Cryptozoön	*Pleurotomaria*	*Gomphoceras*
Leptæna	*Euomphalus*	*Bathyurus*
Metoptoma	*Calaurops*	*Ribeiria*
Trochonema	*Cyrtoceras*	

The total thickness of division *D* is 375 feet.

Division *E* has fine-grained magnesian limestone in beds one or two feet in thickness, weathering drab, yellowish, or brown. Occasionally pure limestone layers occur, which are fossiliferous. Rarely thin layers of slate appear, which also are sometimes fossiliferous.

Here, as in *D* above, we have observed *Murchisonia, Euomphalus, Orthoceras, Lituites*, and *Bathyurus*. To them are to be added two genera of encrinites represented by columns and plates, together with *Strophomena, Bucania, Primitia,* and *Stenopora*—six genera not previously mentioned—making in the whole forty-one genera for the Calciferous.

Division *E* has a thickness of 470 feet.

For all the divisions of the formation we have a total of 1,800 feet.

Sections.

Exposures at the various points offer opportunity for making sections exhibiting the character and thickness of the rocks of the formation. Of the sections observed and measured, only one or two can be described somewhat in detail; the others, though in almost every instance presenting some instructive features, must for the present be passed with a few words.

East Shoreham Section.—It was from a typical section in East Shoreham that the lithological peculiarities previously described were taken; the faunal characteristics, however, are those observed at various localities.

This section represents one of those rare exposures in which not only the strata of the Calciferous, but the whole Lower Silurian, from the Potsdam to the Utica slate, can be seen in one continuous series. This locality was first pointed out by Rev. Augustus Wing, and was referred to by him as "the Bascom ledge."* It is a great monoclinal, two miles in width and three to five miles in length, in which all the Lower Silurian strata are seen, with at least two hundred feet of Potsdam sandstone at the base. The strike is somewhat sinuous, and the dip varies from N. 9° to 38° E., but there are no abrupt changes except at the northern and western borders. Much of the rock is covered with soil, but exposures on the hill-sides, along the water courses, and in the escarpments of cliffs are sufficient to reveal the character and thickness of all the members of the Calciferous formation.

Shoreham Center Section.—Another uplift in which all the strata of the Calciferous are to be seen occurs in a tract extending from Shoreham Center northeast about two miles to Newell's mills. It consists of an anticline with the Potsdam on the axes, and with the superjacent Chazy and Black River formations, bearing characteristic fossils, on the western side.

Orwell Section.—In the town of Orwell, which lies directly south of Shoreham, the upper members of the Calciferous are brought up in an anticline. About two miles northeast of the village, in the bed of a stream—the North branch—the anticline is so much abraded that all the lowest strata of division *C* are seen.

Fort Ticonderoga Section.—In the northwest corner of the town of Orwell, five miles southwest of Shoreham village, is a hill known as Mount Independence. It rises nearly 200 feet above Lake Champlain and is about a mile in length, the top along the north half being a smooth plain sloping gently northward. This plateau was the old parade ground of the soldiers of Fort Ticonderoga, which stood across the lake only half a mile to the north. In fact the promontory on which the fort was built is but the continuation of Mount Independence, after an interval of 88 rods of water, and extends over a mile farther northwestward.

This whole tract of historic ground consists of Calciferous strata, over 1,300 feet in thickness, dipping north at an angle of 6°. The plateau on the north end of Mount Independence is the top of division *B*; the thin-bedded sandstones at the base of division *C* having probably been removed by glacial action, not only here but also farther north, where is now the basin of the lake. The upper layers of *B* are largely quarried and used for a flux in the iron furnaces. On the New York side, in a steep cliff at the end of the

* Am. Jour. Sci., 3d Ser., Vol. XIII, 1877, p. 343.

promontory, appear the remaining beds of *C*—magnesian limestone interstratified with sandstone. The ruins of the fort, 50 or 100 feet above the lake, are on the mottled limestone at the base of *B*, containing *Ophileta complanata*, Vanuxem, and a large *Orthoceras*. One hundred rods farther northwest, the railroad tunnel is cut through the magnesian limestone of *D*, and above the tunnel at the north end appears the banded sandstone of *D*. These and the superjacent strata are best seen farther west on the steep southern slope of the promontory, until finally, 40 rods southwest of the forks of the road, we reach the drab limestone of division *E*, whose sudden change in dip (N. 23° E.) and strike (N. 60° W.) indicates approach to some scene of disturbance. Farther east, north of the main highway, there are other exposures of the drab-colored limestone. These drab-colored limestones are fossiliferous, carrying a form like *Stenopora fibrosa*, Goldfuss, *Euomphalus*, and undescribed species of *Orthoceras*, *Cyrtoceras*, and *Lituites*.

Southeast Charlotte Section.—Twenty miles north of old Fort Ticonderoga, at Thompson's point, is another remarkable display of nearly all the members of the Lower Silurian. It is another monocline, dipping from 12° to 20° to the southeast. It is especially interesting, for in division *D* occur the Fort Cassin series of rocks and fossils. In *E* are found the Cove islands, which offer forms of *Primitia*.* On the bluffs on the shore, also, undescribed species of *Primitia* are found in the strata underlying the Chazy.

Providence Island Section.—At Providence island, 24 miles north of Thompson's point, there is an interesting exposure of the upper part of division *D* and the lower part of division *E* of the Calciferous rock. The main body of the island dips to the northeast, and successive beds are displayed along the shore. Special points of interest connected with this section are the occurrence of the Fort Cassin fossils in division *D*, represented by the group *Calaurops lituiformis*, Whitf., *Maclurea affinis*, Bill., *Lituites eatoni*, Whitf., *Nautilus kelloggi*, Whitf., and the Shoreham fossils of *E* represented by *Murchisonia confusa*, Whitf., *Bucania tripla*, Whitf., *Primitia seelyi*, Whitf., with undescribed gasteropods and cephalopods. The total thickness of *E*, 450 to 500 feet, corresponds well with the thickness observed farther south.

The Fort Cassin Strata.

In 1885 we found on the site of Fort Cassin, isolated on the peninsula at the mouth of the Otter, a locality rich in a fauna chiefly new to science, 31 new species being distinguishable, with still others too poorly preserved to be described with accuracy. This group then seemed to us more nearly related to the forms we know in connection with the upper division of the

* Bulletin Am. Mus. Nat. His., Vol. II, 1878–'90, pp. 58–60.

Chazy (*C*). They were described in the Bulletin of the American Museum of Natural History, Vol. I, No. 8, as Birdseye; and here we rested.

We are convinced now that these Fort Cassin rocks, with their numerous fossil forms, belong to the upper part of division *D* of the Calciferous. We base our opinion on the frequent identity of genera and species, the close lithological resemblance with the rocks known to be of horizon *D*, and the entire absence of the Fort Cassin rocks along the lake where the Birdseye ought to appear if it exists in Vermont.

The Canadian Exposures.

Brief reference may be made to the Phillipsburgh series, which extends four or five miles into Vermont. Logan's division *A*, with its three subdivisions, 700 feet in thickness,* is lithologically identical with our divisions *A*, *B*, and *C* respectively of the Calciferous. The remarkable fossil, *Cryptozoön steeli* (n. sp.), we have observed in the reticulated limestones of *A* 2 at Phillipsburgh. Similarly, the first four members of Logan's division *B* correspond to our division *D*, both in lithological character and in fossils.† The beds of Calciferous sandstone are as prominent and peculiar at Phillipsburgh as at Shoreham. The magnesian beds of our division *E* are, however, but poorly represented in the lower part of Logan's division *B* 5, but in a similar way they thin out and disappear in the eastern part of Addison county, Vermont. The higher beds of *B* 5 at Phillipsburgh, and the beds of *C* 1 seem to be represented in western Vermont, but by the lower beds of the Chazy.

A similar comparison might be made between the Calciferous of Lake Champlain and the 1,830 feet of strata on the northwest coast of Newfoundland (divisions *D* to *L* of the Geology of Canada).‡

Misapprehensions Corrected.

In connection with this discussion, various misapprehensions regarding some of the rocks of Vermont should be mentioned and corrected. In the Vermont Report, volume I, 1861, pp. 267–269, certain slates are described as belonging to the Calciferous group. One exposure is cited in the extreme southwest corner of Shoreham, and another, farther south, in Orwell, with ledges running along the lake shore. The rocks in both of these localities have afforded fossils of the Utica slate. So these slates of Vermont must disappear from the Calciferous formation.

* Geol. of Canada, 1863, p. 844.
† Loc. cit., pp. 278–279.
‡ Loc. cit., p. 865, et seq.

We have observed slate only in division *E*, and here it occurs in thin bands or layers, rarely carrying *Ostracoda* of different species.

Another point: Professor Emmons, in writing of the Birdseye formation,* says:

> "The name, it is true, is not very appropriate, and besides there are other limestones to which the term Birdseye has been given, but they are not likely to be confounded with the Birdseye of the Champlain group."

But the mischief is that other rocks are thus confounded. A rock in *B* of the Calciferous answers Professor Emmons lithological description of the Birdseye, and Vanuxem † uses the very term in distinguishing a portion of the Calciferous which is probably *B*, though he uses it to describe texture and not to distinguish horizon. Again, the blue limestone of the upper part of *D* of the Calciferous has the appearance and characteristic features of the Birdseye, yet carries the abundant fauna of the Fort Cassin rocks.

A third horizon, below the true Birdseye, is that occurring in *C*, the upper division of the Chazy. *Calymene multicosta*, Hall, and *Illænus crassicauda*, Dalman, found at Isle la Motte, are assumed in the Paleontology of New York, volume I, 1843, pp. 228–229, to be in the Birdseye. They belong, however, to the dove-colored limestones of the upper Chazy, which elsewhere underlie strata over 75 feet thick, composed largely of *Rhynchonella plena*. *Calymene* is found at the same horizon elsewhere on the lake. *Cyrtoceras boycii*, Whitf., *Soa* (?) *lamottensis*, Whitf., and *Lichas champlainensis*, Whitf., belong also to the same bed of the upper Chazy.

The Birdseye formation is very scantily represented in Vermont. *Phytopsis tubulosum*, Hall, has been seen only in the northwest corner of Benson, and in a bed only about six feet thick. Elsewhere we find in this horizon only a few feet of pure, fine-grained, brittle limestone, with fine lines of calcspar, without fossils, lighter in color than the known Black River strata just above.

Recapitulation and Suggestions.

As indicated at the beginning of this discussion, our study of the Calciferous formation has brought us a series of surprises. The first was the thickness of the rocks. It was only after repeated measurements that we were willing to accept the fact that we were dealing with a series of rocks but little less than 2,000 feet in thickness. This, too, at a horizon where the very existence of a formation worth the name was a matter of question.

The amount of magnesian limestone both surprised and perplexed us. The masses of the various divisions are so alike that the attempt to place them was at first discouraging; but as we became familiar with the succession

* Geology of N. Y., Report 2d District, 1842, p. 157.
† Geology of N. Y., Report 3d District, 1842, p. 30.

of fossil-bearing rocks interbedded with them the difficulty in a large measure disappeared. They can best be recognized by their relation to the superjacent and subjacent beds, their lithological differences affording unsatisfactory distinctions.

The amount of pure limestone was another surprise. These pure masses are most noticeable in division *B;* and the fact of its great abundance suggests the inquiry whether a portion of the marble lying near the flanks of the Green mountains may not be metamorphosed Calciferous.

A suggestion in this immediate connection is that the sandstones and sandy limestones of division *C* and those of the lower part of *D* gave the name Calciferous to the formation. The fucoids, so far as we have seen, are not characteristic of any one division, though they appear abundantly in various horizons of *D.* Further, *Scolithus* cannot be regarded as indicating a Potsdam horizon, as the most abundant display that we have ever seen is to be found at the bottom of division *C,* six or seven hundred feet above the Potsdam sandstone.

A great surprise awaited us in the abundance of the fossil forms. The 40 and more genera, represented by over a hundred species, was an unlooked-for result. Some limestone bands are packed with fossils; while the sandstones as well as magnesian limestones, which at first were thought to be barren, contain both obscure and distinguishable fossils. The collection we have made is to be regarded rather as a preliminary than a complete one. A wide field for the study of paleontology is opened before us. Forms that were supposed to exist only at higher horizons are found to descend more nearly to the primordial zone.

The discovery of Utica fossils in the slate supposed to belong to the Calciferous simplifies the study of the formation by leaving out one perplexing factor.

The almost entire exclusion of the Birdseye formation from the Vermont rocks was a result unexpected.

The exact horizon of the Fort Cassin rocks seemed a simple problem, and one we set ourselves to solve. Assuming the rock and fossils so like Birdseye to be Birdseye, it appeared only necessary to find localities where the upper Chazy approaches the Black river; and between would be the rock and the fossils we were seeking. But in every such locality we found the Black river directly above the Chazy with no room for the Birdseye. But we did find other exposures of the Fort Cassin rocks. And at what horizon? Challenging our belief with a sensation like a violent shock, there appeared Calciferous below, Calciferous above. These rocks then dropped down to the upper member of division *D,* a fall of 1,000 feet; and their fauna went to swell the increasing number of the Calciferous.

The fossils sometimes figured as sections of the stem of *Phytopsis tubulosum*, Hall, and so regarded as indicative of the Birdseye, had previously been shown by one of us to be really a little sponge, *Strephochetus*, not a Birdseye fossil at all, but one characterizing the middle Chazy. So this perplexity disappeared.

It must have been on lithological rather than stratigraphical grounds that *Calymene multicosta*, Hall, *and Illænus crassicauda*, Dalman, were placed in the Birdseye of Vermont. As has been previously stated, the rock carrying these fossils belongs to *C*, the upper member of the Chazy, and is beneath 75 feet of *Rhynchonella* rock.

So the Birdseye has been retreating from Vermont, retreating upwards; crowded out form Calciferous *B*, Calciferous *D*, Chazy *B*, Chazy *C*, it finds no standing room except over a few square rods within the state. With its departure we are rid of a source of perplexity and confusion.

The correlation of the Calciferous of the Champlain valley with that of the western states offers a subject for interesting investigation. This cannot be entered upon here.

Attention may, however, be called to the distribution of the eastern Calciferous, which spans the country like an irregular bow from near Long island to the island of Newfoundland, rocks of similar character appearing in the valleys of the Hudson and St. Lawrence as well as that of the Champlain, suggesting that the same physical conditions of sedimentation and like forms prevailed from New Jersey to Labrador, the deposits marking the position of an ancient sea beach not far from the borders of the Archean terrane. The most magnificent development, however, appears in the Champlain valley.

A suggestion may be offered in regard to names. In consideration of the fact just stated—that of a wonderful deposit of a series of well characterized rocks, 1,800 feet in thickness and bearing a fauna that will in all probability soon reach up into the hundreds of specific forms, and this overlain by the Chazy with its 700 feet of rock crowded in many parts of its three divisions with distinct and characteristic fossils—may not the rocks of this group have a name of their own rather than the misleading one "Canadian"? They are worthy of one.

In the time allotted, only an inadequate presentation of a subject so broad could be expected. We must reserve to ourselves the right of taking other opportunity and other means of discussing the topic at a length its importance demands.

Middlebury, Vt., December, 1889.

DISCUSSION.

Mr. C. D. WALCOTT: The authors have stated in their paper that the Calciferous terrane has a thickness of 1,800 feet in the Shoreham section, between the Potsdam sandstone and the Chazy limestone, and that there are, probably, 700 feet of the Chazy limestone in the valley of Lake Champlain. Heretofore 300 or 400 feet of strata have been assigned to the Calciferous, and not much more to the Chazy. One of the breaks in our knowledge of the lower Paleozoic rocks of the Champlain valley has been that which is now covered so thoroughly by these sections.

Reference is made in the paper to the section at Pillipsburgh, Canada, given by Logan in 1863. This section has a thickness of 1,890 feet. The base and summit of the section were not defined, as Logan did not observe either contact. During the past summer I found, on Lake Champlain, a small outcrop of Potsdam sandstone, with characteristic fossils, subjacent to the limestone of the Calciferous terrane. I measured the section through to the summit of the Chazy zone, and it gave a thickness of 1,750 feet, with one hiatus caused by a fault in the Calciferous portion. The Calciferous fauna ranges through the lower portion of the section and passes into the Chazy fauna about 1,400 feet from its base. It is impossible to draw any line of division between the Chazy and Calciferous in the Pillipsburgh section by stratigraphic or paleontologic evidence.

The authors state that this series of rocks has been traced south to the New Jersey line and north to Phillipsburgh, Canada. During the past field season I examined the Phillipsburgh section and then went to Quebec, on the St. Lawrence, where the limestones have nearly all disappeared and the shales form most of the section. There is a band of limestone near the base that carries the same fauna that I found in the middle portion of the Calciferous part of the Phillipsburgh section. As the Point Lévis graptolites occur in the shales immediately associated with the limestone, this identifies the graptolitic fauna as of middle Calciferous age. In the bed of limestones at Point Lévis there are numerous fossils in the lighter colored limestones in which I found fossils of the upper Cambrian or Potsdam age. Tracing the Calciferous from New Jersey across Pennsylvania and Virginia into Tennessee, we find the same series of rocks, which are there known as the Knox dolomite. I crossed the section in Tennessee a few weeks after studying the Phillipsburgh section and recognized the upper Chazy zone, and then the change of fauna that passes into the Calciferous. At the base of the Knox dolomite the upper Cambrian or Potsdam fauna is found in the Knox shale just as it is found, in the Phillipsburgh section, in the Potsdam sandstone at the base of the Calciferous. The Knox dolomite, I believe, is given a thick-

ness of from 3,500 to 4,000 feet by Safford. These several sections prove that in the Appalachian region, extending from Georgia to the St. Lawrence river and also to Newfoundland, there is a great development of limestone between the Potsdam zone and the Trenton limestone which may be referred to the Calciferous-Chazy zone, or the Canadian period of Dana.

I think we owe to President Brainerd and Professor Seely our sincere thanks for the valuable work they have been doing in the geology of the valley of Lake Champlain.

Professor C. H. Hitchcock: Reference was made by Professors Brainard and Seely to the work of their predecessors recorded in the geological report of the state of Vermont. I was concerned in that, and I should like to explain a matter in reference to it, as I think perhaps the part we took is not clearly understood. I was the assistant appointed for that portion of the state at the very beginning of my scientific career, going directly from Professor Seely's recitation room. With the limited means at our disposal we made no effort to study these rocks thoroughly. We practically followed through the Champlain valley the results of Adams and Thompson, who preceded us, and therefore we did not see the great thickness of limestone that is represented by these sections.

But there is another part of our work that I venture to take into account. When we examined the limestones further east, which were called Taconic, we came to the conclusion that they were practically the same thing as these limestones directly on Lake Champlain, but we could not correlate them because their thickness was so much greater, and therefore we gave to them a special name—the Eolian limestone. The section of the Eolian limestone corresponds with that given by the authors of this paper, being 2,000 feet in thickness. The area in Shoreham was colored on our map as the Eolian limestone, and thus we were in accord with these later conclusions, although we used a different name.

THE FORT CASSIN ROCKS AND THEIR FAUNA.

BY R. P. WHITFIELD.

(*Read before the Society December* 27, 1889, *as a Supplement to the Memoir on the Calciferous Formation in the Champlain Valley by Professors Brainard and Seely.*)

About three years ago, as was mentioned by Professor Seely, I published in a Bulletin of the American Museum a series of fossils from Fort Cassin, Vermont, and in that connection referred them to the horizon of the Birdseye limestone, partly on paleontological grounds, and to some extent on the apparent stratigraphical relations of the beds in which they were found.

When the fossils came to me first, they were thought to be from the Trenton limestone, but on a cursory examination I could find no species among them which I could identify with any Trenton forms that I had ever seen. After studying them, I visited Fort Cassin in company with Professors Brainard and Seely, and spent about three hours at that locality. In looking at the beds then I became convinced they could not be true Trenton; also that they could not be very much lower in the series. After examining the rocks at that point we visited the *Maclurea* beds at a locality (Appletree point) 63 rods further north, and the next day another locality four miles to the south. This last proved to be Trenton limestone, and contained Trenton fossils.

The Fort Cassin beds are characterized by a fauna consisting largely of cephalopods, with many gasteropods and a few brachiopods. One of the cephalopods appeared to be identical with the form described by Professor Hall as *Orthoceras bilineatum*, and referred to the Birdseye limestone. The general character of these fossils appeared to be the same as that of those from the lower part of the Trenton group, namely, the Black River or Birdseye limestone; and the character of the *Lituites*, none of which were, however, identical, was also very similar. The orthocerata, other than *O. bilineatum*, Hall, were entirely new, and the occurrence of *Gomphoceras* in these beds was a very peculiar feature, at least for an American locality, as it had not hitherto been found below the Niagara group. The gasteropods were as peculiar in their character as the cephalopods, and we have a number of genera, all of which characterize the Trenton group throughout, except *Maclurea*, and none of which had been found below the Chazy limestone, except by the Canadian geologists, who referred them to the Quebec group. Among these were a number of nearly identical, or

what might be called representative, forms of those described from Newfoundland, and referred by both Sir Willam Logan and Mr. Billings to the Quebec group. But from the fact that of so many of the forms referred to the Quebec, the true horizon of which is doubtful, it seemed best not to consider them as of stratigraphical value.

A few of the species were also similar to forms from the Phillipsburgh section, which Logan referred to the Quebec and Billings to the Calciferous. After studying these fossils I concluded they were more nearly analogous to those of the lower Trenton than to anything below that horizon, and after examining the Fort Cassin section it appeared as if they could be but little above the *Maclurea* beds of the Chazy, as the *Calaurops* layer, which is fifteen feet below the Fort Cassin fossil layer, appears by the Fort Cassin section to come just above the *Maclurea* beds of Apple-tree point, 63 rods further north; and no other explanation can be given of this without the supposition of a fault occurring between these two points.

Taken from a paleontological point of view, based upon the previously known faunas exclusive of those referred to the rather troublesome Quebec group horizon, it would appear impossible to place these beds at any horizon other than that of the base of the Trenton group, namely, the Birdseye limestone. But from evidences brought forward by President Brainard and Professor Seely, as shown in their Ticonderoga and Shoreham sections, it appears that they are undoubtedly below the *Maclurea* beds of the Chazy limestone, and that a fault must exist where none was suspected.

My object in calling attention to this matter at this time and in this way is chiefly to make a correction of the reference of this group of fossils and to have it placed on record as such. But whether the beds are to be called Calciferous or not will depend entirely upon where the line between the Calciferous and the overlying Chazy shall be drawn. A visit with Professor Seely, a year later, to Beekmantown, New York, on the opposite side of the lake, a few miles north of Plattsburg, where the true Calciferous, well developed and abundantly characterized by its own fossils, the *Ophileta complanata* and accompanying gasteropods, failed to show anything of the Fort Cassin fauna.

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PROCEEDINGS OF THE ANNUAL MEETING HELD AT NEW YORK DECEMBER 26, 27 AND 28, 1889.

J. J. STEVENSON, *Secretary*.

CONTENTS.

Session of Thursday, December 26.

The Society met in the American Museum of Natural History; President James Hall in the chair, and a large number of Fellows and guests present.

The President called the Society to order at 10 40 a. m., and introduced Morris K. Jesup, Esquire, President of the American Museum of Natural History, who welcomed the Society and gave a brief statement respecting the character and purposes of the Museum, showing how closely it is related to work such as is done by the Geological Society. President Hall replied, acknowledging the courtesy of the Trustees of the Museum, and recalling some interesting facts to show the early prominence of New York as a scientific center.

The minutes of the meeting held at Toronto on August 28, 1889, were read by the Secretary and approved; after which the report of the Treasurer was read. It showed a balance of $1,716 in the treasury.

The Secretary read the results of ballot for new Fellows, as follows:

Frank Dawson Adams, Montreal, Canada, lately of Geological and Natural History Survey of Canada, now Lecturer at McGill College, Montreal.

Victor Clifton Alderson, 6721 Honore Street, Englewood, Ill., Teacher of Geology.

Henry M. Ami, Ottawa, Canada, Assistant Paleontologist to Geological Survey of Canada.

Albert Smith Bickmore, American Museum of Natural History, New York city, formerly Professor of Natural History at Madison University, now Professor of Natural History, Curator of Anthropology, and Secretary of the American Museum of Natural History, and engaged in lecturing on Geology and Physical Geography.

Ezra Brainerd, Middlebury, Vt., President of Middlebury College.

Aaron Hodgman Cole, Hamilton, N. Y., Lecturer on Natural History at Madison University, and now engaged in Study of Invertebrate Paleontology.

Thomas Sterry Hunt, New York city, formerly of Geological Survey of Canada, now engaged in Chemical Geology.

R. D. Lacoe, Paleobotanist, Pittston, Pa.

Alfred Church Lane, Houghton, Mich., Assistant on Geological Survey of Michigan, and engaged in Petrography.

Daniel Webster Langdon, Jr., Cincinnati, O., formerly Assistant on the Alabama Survey, now Geologist of Chesapeake and Ohio Railway Company.

Alfred Richard Cecil Selwyn, Ottawa, Canada, Director of the Geological and Natural History Survey of Canada.

George Clinton Swallow, Helena, Mont., formerly State Geologist of Missouri and also of Kansas, now Inspector of Mines of Montana.

Bailey Willis, Washington, D. C., in charge of the Appalachian Division of the U. S. Geological Survey.

J. E. WOLFF, Cambridge, Mass., formerly Assistant on N. Transcontinental Survey, Assistant in N. E. Division of the U. S. Geological Survey, now Instructor of Petrography at Harvard College.

LORENZO G. YATES, Santa Barbara, Cal., Botanist, engaged now in Study of Fossil Mammals of Pacific Coast, respecting which he has published numerous papers.

The result of ballot for officers for 1890 was announced as follows:

JAMES D. DANA, *President*.
JOHN S. NEWBERRY, ALEXANDER WINCHELL, } *Vice-Presidents*.
JOHN J. STEVENSON, *Secretary*.
HENRY S. WILLIAMS, *Treasurer*.
J. W. POWELL, GEORGE M. DAWSON, CHAS. H. HITCHCOCK, } *Members-at-large of the Council*.

The Secretary announced the death of three Fellows of the Society, George H. Cook, David Honeyman, and Charles A. Ashburner. He was authorized to publish the following notices in the Bulletin:

OBITUARY NOTICES.

Professor GEORGE H. COOK died suddenly of heart failure on September 22, 1889. He was born at Hanover, New Jersey, on January 5th, 1818. In 1836 he became a civil engineer, and his first work was in laying out the line for the Morris and Essex railroad. He also surveyed the line for the Catskill and Canajoharie railroad. He was not, however, satisfied with his attainments, and entered the Troy Polytechnic Institute in 1838, graduating in 1839. He afterward became a teacher in the institute, and in 1842 he was made "senior professor," an office equivalent to that of president elsewhere. He afterward became professor of mathematics and natural philosophy in the Albany Academy. In 1851 he became principal of the academy, and held the office two years, until his election to the chair of chemistry and natural philosophy in Rutgers College. The next year he was made assistant geologist of New Jersey, which position he held for three years. The office of state geologist had been allowed to lapse for several years, but a paper read by Professor Cook before the legislature, in 1864, led to its reörganization and to his appointment as its head.

Professor Cook's work as state geologist was varied and of great importance. The topographical maps of the state which have been published under his supervision have been adjudged to be among the best published by the different states. The last of the series was recently issued, and

Professor Cook was at the time of his death engaged on his final report. Two volumes had been prepared and are now in print.

In 1864 the State Scientific College was attached to Rutgers College, and Professor Cook, while retaining his professorship, became vice-president of the state college. He organized the State Board of Agriculture, and was for a long time its secretary. He became in 1886 chief director of the New Jersey State Weather Service. He was long president of the New Brunswick Board of Water Commissioners. He was also a member of the State Board of Health, and held many minor offices in the state. He was active also in work elsewhere. In 1852 he was sent to Europe by the state of New York to make investigations that might aid in developing the Onondaga salt springs. He went again to Europe in 1870 to study certain geological questions. He was a member of the National Academy of Sciences, and the author of many papers and addresses. He received the degree of Ph. D. from the University of New York, and the degree of LL. D. from Union College.

"A friend whose devotion never waned, a loyal citizen ready for every duty, a true scientist and a manly christian, he has left an example for us if we would make the world better and wiser."

Rev. DAVID HONEYMAN, D. C. L.,* was born at the village of Rathillet, in the northern part of the county of Fife, Scotland, in the year 1814. He was educated at the University of St. Andrews, on the east coast of the same county. At college he devoted special attention to Hebrew, and was early recognized as a Hebrew scholar; but, even in youth, his attention was attracted to geology, as was that of many other young men in the locality, at a time when Sir Charles Lyell was laying the foundations of his life work (one of his earliest publications being a geological section of the adjoining county of Forfar) and Hugh Miller was developing the paleontological riches of the Old Red Sandstone rocks of the northern shores.

Honeyman's first geological work was in connection with the Museum of the Watt Institution of Dundee (one of the early Scotch "mechanics' institutes"), for which he, in conjunction with others, brought together and arranged collections of mineral and rock specimens and fossils. In 1851 he left Scotland for Nova Scotia, and took the chair of Hebrew in the Halifax Free Church College. After a brief term at Halifax he accepted the pastorate of the Presbyterian congregation of Shubenacadie, in the same province, and, thereafter, that of Antigonish, from which he was released in 1859. After this retirement he continued to conduct services occasionally, but did not accept a settled charge, devoting his time chiefly to geological and other

* By Professor Geo. Lawson, of Dalhousie College.

scientific work. He examined particularly the geology of Cape Breton and the eastern counties of Nova Scotia, paying special attention in later years to glaciation and transported materials. Many of his observations were published in the Proceedings of the Institute of Natural Science of Nova Scotia. Much of his work was brought together, a few years ago, in a small work entitled "Giants and Pygmies."

Dr. Honeyman acted as executive officer of the Nova Scotia government at several of the great international exhibitions held in the United States and Europe, at which the products of Nova Scotia were shown. He was for many years curator of the Provincial Museum at Halifax. He delivered several courses of lectures on geology in Dalhousie College, Halifax. The University of King's College, Windsor, Nova Scotia, conferred upon him the degree of D. C. L.

On Thursday, the 17th October last, he closed the museum as usual at 4 p. m., chatted in his customary lively manner with those he met on his way home, when he was seized with apoplexy and dropped on the sidewalk. He recovered consciousness momentarily and remarked, "That was very sudden;" but, within ten or fifteen minutes, although in the hands of two able physicians, he passed away, leaving a sorrowing widow and four daughters. His remains were accompanied to the Halifax cemetery by a very large procession of leading citizens, on Sunday, 20th October.

G. L.

CHARLES ALBERT ASHBURNER, Sc. D. (University of Pennsylvania),* was born in Philadelphia, February, 1854, and educated at the Friends' Central School, and the Philadelphia High School. In 1870 he entered the Towne Scientific School of the University of Pennsylvania, and was graduated in 1874, at the head of his class, delivering the valedictory on commencement day.

While an undergraduate he was one of the aids on a hydrographic survey of the Delaware river. After graduation he served in the U.S. Light-House Survey Corps; and was commissioned, in 1874, aid to Mr. John H. Dewees, Assistant Geological Survey of Pennsylvania for the Juniata river district. With his classmate and fellow aid, Mr. C. E. Billin, he made a contour line survey of the southern slope of Jack's mountain, and the underlying vales, to determine the outcrops of Clinton fossil ore beds, extending from Lewistown south to Orbisonia, and west to the summit of the East Broad Top coal basin. Maps and many beautifully constructed measured cross-sections, local maps of the fault in Black Log gap and of the curious downthrow at

* By J. P. Lesley.

Three Springs, etc., were published in Report F, in 1878, as illustrations of their excellent geological and topographical work. Mr. Ashburner's sensible and full report of it, supplementary to and separate from the special report of Mr. Dewees on the ore, will be found in the last half of the volume.

Having thus shown great ability in reading and portraying the geology of one difficult district, Mr. Ashburner was commissioned in 1876 to survey McKean, Elk, Cameron, and Forest counties on the northern border of the state, where the development of the petroleum production in the Bradford field was becoming of extraordinary importance, soon to overshadow that of all other oil fields previously or subsequently exploited. This survey occupied him and his aids two years, and his able report upon it (R) was published in 1880, well illustrated with local maps and sections, a colored geological map of each county, and a topographical map of McKean county in contour lines. His second report (R 2) on Elk, Cameron, and Forest counties, published in 1885, exhibited broad views and sound deductions from surface facts and boring records, which became of great importance to the community, and started him on a career of oil and gas investigation which afterwards extended over a large part of the United States and Canada. His determination of the various rates of increment of the formations intervening between the conglomerate above and the oil-bearing Chemung below had much influence on the depths to which subsequent experimental borings were carried. His differentiation of the conglomerate was also an important contribution to geology.

In 1880 he was directed to go to the eastern part of the state and plan a survey of the Anthracite region as a whole; and in 1881 he organized a complete corps of assistants, established offices at four centers, and began the systematic survey which has shed such lustre on the Geological Survey of Pennsylvania. Its successful prosecution, in one basin after another, year after year, until he tendered his resignation in 1887, was due entirely to his genius for geological work of the highest order, to his disciplined judgment in dealing with men of all ranks and occupations, to his high sense of personal honor, and to his kindness of heart.

In the fall of 1886 he resigned his commission to become the scientific expert of the Westinghouse Fuel Gas and Electrical Engineering Company at Pittsburg, for which he visited various districts of the United States which the universal search for natural gas in turn invaded; and he thus became an authority of the first rank in this branch of geology.

He was also required to pass judgment upon properties on which mining of the precious metals was proposed, especially in the far west. On his last return from the copper district of Arizona he fell ill and suddenly died, December 24, 1889, in the thirty-sixth year of his age, universally esteemed and respected in his profession and in private life.

His principal record was made by his reports to the state geologist of Pennsylvania, but he published many papers in the transactions of the American Institute of Mining Engineers, of which he was a zealous member and officer; as also of the American Philosophical Society, American Society of Mechanical Engineers, Academy of Natural Sciences, American Geological Society, and American Association for the Advancement of Science.

J. P. L.

Some general announcements were made, after which the President announced the first paper of the meeting, entitled—

SOME ADDITIONAL EVIDENCES BEARING ON THE INTERVAL BETWEEN THE GLACIAL EPOCHS.

BY PRESIDENT T. C. CHAMBERLIN.

The communication was discussed by Mr. W J McGee, Professor John R. Procter, Professor I. C. White, Mr. F. J. H. Merrill, and President Chamberlin. The communication and discussion are printed in full among the memoirs, forming pages 469–480 of this volume.

The Society then listened to a paper on—

TERTIARY AND CRETACEOUS DEPOSITS OF EASTERN MASSACHUSETTS.

BY N. S. SHALER.

This communication was discussed by Mr. G. K. Gilbert. It will be found among the accompanying memoirs, pages 443–452.

In the absence of the author, the next paper was read by title:

ON GLACIAL PHENOMENA IN CANADA.

BY ROBERT BELL, B.A.SC., M.D , LL.D., ETC.

It will be found printed in full among the memoirs, pages 287–310.

After a short recess the Society reässembled and listened to the oral communication represented by the following abstract:

THE LARAMIE GROUP.

BY J. S. NEWBERRY.

(*Abstract.*)

The Laramie group was named by Mr. Clarence King and defined in his "Systematic Geology," volume I of the Report on the Geology of the Fortieth Parallel, 1878. The name was accepted by Dr. Hayden but differently applied, since, contrary to the usage and judgment of Mr. King, he included in it the Fort Union group. Dr. Hayden at first called his compound Laramie Tertiary, but he subsequently designated it post-Cretaceous.

The Laramie group proper, as defined by King, consists of a series of shales, sandstones, and beds of coal, largely developed in Colorado, Utah, and Wyoming. It is well exposed on the east side of the Rocky Mountains in a belt that reaches as far north and south as explorations have been made. I have myself traced it nearly to the southern line of Chihuahua and as far north as the Canadian boundary; throughout this region it is a great coal-bearing belt. Along the line of the Pacific railroad it is exposed at Point of Rocks, Black Butte, Bitter Creek, Evanston, and elsewhere, and the coal mines at these places are all opened in it. On the west side of the Rocky Mountains also it is coal-bearing, and is known to extend interruptedly from the San Juan river to and beyond the Union Pacific railroad. At Crested Buttes, Coal Basin, Newcastle, and other points it contains a number of thick and very pure coals which vary in character from hard, bright anthracite to non-coking bituminous coals, this variation being dependent upon igneous rocks which sometimes cut through, sometimes underlie, and sometimes have overflowed the coal beds. From the Rocky Mountains in Colorado the Laramie extends westward to the Wasatch, and everywhere contains beds of coal, some of which have been worked at Cedar City, Castle Valley, Pleasant Valley, Coalville, and elsewhere.

The Laramie formation has in the Raton mountain, according to Mr. R. C. Hills, a thickness of nearly 5,000 feet. At Trinidad, Walsenburg, Florence, and north of Denver at Marshalls's and at Erie, in all of which localities its coals are worked, it is much thinner, the upper portion having been removed by erosion. In Table mountain, near Golden, this upper portion has been protected by a trap overflow, and a thickness of perhaps 3,000 feet of strata is shown, all of which belongs to the Laramie. On the west side of the Rocky Mountains, at Coal Basin, Newcastle, and elsewhere, the Laramie shows a thickness of from 3,000 to 4,000 feet. The beds are here highly inclined; but in Monument mesa, between Grand river and the Gunnison, the strata are nearly horizontal and are overlain unconformably by fresh-water Tertiary beds.

The relations of the Laramie group have been much discussed, and perhaps no portion of the geological column of North America has given rise to a greater amount of literature or a greater diversity of opinion among geologists. This, for the most part, has arisen from the fact that many writers on the subject have combined two distinct formations in the Laramie and have called them one, when they have almost nothing in common, belong to different geological systems, and should never have been united.

Dr. F. V. Hayden, who spent so many years in studying the geology of the country bordering the upper Missouri, made large collections of fossil plants from the Fort

Union group at Fort Union, on Tongue river, on Amil's creek, and in other places, all of which he placed in my hands for study. Most of these I described in the annals of the New York Lyceum of Natural History in 1869. I called this flora Tertiary, and made it Miocene because I identified in it many species of plants collected on Mackenzie river, in Greenland, Spitzbergen, and various European localities described by Professor Oswald Herr in his *Flora Fossilis Arctica*, and called there Miocene, but since shown by Mr. J. Starkie Gardner to be Eocene.

Mr. Leo Lesquereux, who was for many years employed by Dr. Hayden to work up the plants collected by the different parties of the Geological Survey of the Territories, following Dr. Hayden, united the Laramie and Fort Union and called the Laramie Eocene and the Fort Union Miocene. Mr. Lesquereux described in Dr. Hayden's annual reports and in volumes VII and VIII of his final report a large number of fossil plants from the Laramie, collected at Placer mountain, New Mexico. the Raton mountains, Fisher's peak (Trinidad), Golden, Marshall, Point of Rocks, Black Butte, and other points. As has been stated, he regarded this flora as Eocene,

In the Sixth Annual Report of the Director of the U. S. Geological Survey (1885) Professor Lester F. Ward published a "Synopsis of the Flora of the Laramie Group." Like Dr. Hayden and Mr. Lesquereux, he unites the Laramie and Fort Union groups and calls them Tertiary but, unlike Mr. Lesquereux, considers the whole Eocene. Professor Ward's material, chiefly collected by himself in the valley of the Yellowstone, is mostly from the Fort Union group, and so his memoir is really and only an important contribution to our knowledge of the Fort Union flora.

In 1875 Professor E. D. Cope discovered in the Laramie group, at Black Butte, the bones of a saurian which he called *Agathaumas sylvestre*. Between and around the bones of this saurian were numerous fossil leaves. Professor Cope pronounced his saurian to be of Cretaceous age, and accepting Mr. Lesquereux's view that the associated flora was Tertiary he says, in the second volume of the final report of Dr. Hayden (page 40):

"There is then no alternative but to accept the result that a Tertiary flora was contemporaneous with a Cretaceous fauna, establishing an uninterrupted succession of life across what is generally regarded as one of the greatest breaks in geologic time."

This paragraph has been frequently quoted, and has been considered by some as proof that the testimony of plants was inconsistent with that of animal remains, and that plants were of little value in deciding the age of strata. Since the publication of Professor Cope's report here referred to I have spent much time in the study of the structure and fossils of the Laramie group in New Mexico, Colorado, Wyoming and Utah. I have made and had made larger collections of the plants of the Laramie than had before been gathered by any one; have compared them carefully with the flora of the Fort Union group; and in two visits to Europe have examined all the principal collections of Tertiary and Cretaceous plants made in England or on the Continent, largely for the purpose of solving the problem of the age of the Laramie as compared with other more or less closely associated formations in this country and in Europe. My purpose in coming before you to-day is to briefly report the results at which I have arrived; and these are:—

First. That the floras of the Laramie and Fort Union groups are totally distinct, and these formations should be referred to different geological systems—the Fort Union to the Tertiary, the Laramie to the Cretaceous.

I have not myself seen a single species common to these floras, and but one has been reported by others, viz., *Trapa microphylla*, found by Lesquereux at Point of

Rocks, and collected by Professor Ward in the valley of the Yellowstone. It does not occur in the collection of Fort Union plants placed in my hands by Dr. Hayden, nor in the large representation of this flora which I have obtained from other sources. Mr. Lesquereux had but little material, so little that I think it would be unwise to hang an important conclusion upon it; but if it should prove that the plants collected by Mr. Lesquereux and Professor Ward are identical, that would be no good reason for uniting floras that are so different in aspect and consist of hundreds of species which are unlike.

Second. The Fort Union flora may be distinguished from that of the Laramie at a glance by its abundant species of *Viburnum*, *Populus*, *Platanus*, and *Corylus*, and it includes several species now living, such as *Onoclea sensibilis*, *Taxodium distichum*, and two hazels which cannot be distinguished by their leaves from *Corylus rostrata* and *C. americana*. It has also the general facies (and several identical species) of the Eocene flora of Bournemouth and the Island of Mull, and should undoubtedly be referred to the same horizon.

Third. The Laramie flora is most like the Paleocene floras of Sezanne, Galinden, and Alum bay, but it is not certain that any of its species are identical. Two ferns, *Anemia subcretacea*, Saporta, and *Lygodium kaulfussi*, Herr, are considered by Mr. J. Starkie Gardner the same with Lesquereux's *Gymnogramme haydeni* and *Lygodium neuropteroides*. This is possible and perhaps probable; but our plants are more robust than the European and may be considered as distinct varieties if specifically identical. It should also be said that both these ferns have wide geographical and vertical range and are believed to occur in both the Cretaceous and Tertiary strata of the Old World. Hence they have little value as means for determining the age of the Laramie. I have fronds of *Lygodium* which I cannot distinguish from the type of *L. neuropteroides* obtained from the lower Laramie, the Green River group, the Current creek beds of Oregon, and the coal-bearing strata of Wikinson, Washington; but the fronds of this genus are very variable in form, and it is quite possible that my specimens represent several species. So I have what Mr. Gardner would probably regard as fronds of *Anemia subcretacea* from Point of Rocks, Ham's fork, Carbonado, and Tschuckernuts, Washington; but most of these are much more robust than the European forms, and constitute at least distinct varieties.

Fourth. The Fort Union flora contains a large number of species found by the Canadian geologists in the "Porcupine Hills" or "Paskapoo" series of rocks, and it is quite certain that they are of the same age; while the "Edmonton series" of Canada is as surely identical with our Laramie. Dr. Dawson's Belly River series also contains a number of Laramie plants, but it is overlain by marine strata containing Fox Hills mollusks. This is a strong argument in favor of the Cretaceous age of the Laramie, and indicates that the Laramie flora was established on the land while the sea near by was peopled with Cretaceous mollusks; that, locally and temporarily the sea invaded the land and laid down marine upper Cretaceous beds over brackish or fresh-water Laramie sediments, afterward retreating so that the surface was again covered with Laramie vegetation. The interlocking of the Laramie and Fox Hills formations is also shown in the Judith river basin and in southern and western Colorado, where species of *Inoceramus*, *Mactra alta* and *Cardium speciosum* occur with Laramie plants. If now to these facts we add the occurrence in the Laramie of many genera and species of dinosaurs and many small mammals of Mesozoic character, as shown by Professor Marsh, the weight of evidence in favor of the Cretaceous age of the formations is overwhelming. This view was long ago advocated by Mr. Clarence King, Mr. F. B.

Meek, Professor J. J. Stevenson, and myself, and the arguments in favor of it have recently been much strengthened.

The relations of the Laramie group to the coal-bearing rocks of Puget sound and Vancouver island are very intimate. They have many species of fossil plants in common, and it is certain that a considerable portion of the ten thousand feet of coal-bearing strata on Puget sound is of Laramie age. The upper part of the series at Bellingham bay contains some Fort Union plants and is doubtless Tertiary.

The relations of the Laramie to the "Lignitic" group of Mississippi are as yet doubtful; a few species of fossil plants are apparently common to both, but the molluscan fauna is entirely distinct. It is to be hoped that the able geologists now at work with so much success in Arkansas and Texas will make collections of the Lignite flora that will permit full comparisons to be made with the flora of the Laramie.

In conclusion, I would say that an effort has been made to distinguish the Laramie from the Fort Union group by assuming that the mollusks of the Laramie are marine or brackish water, while those of the Fort Union are fresh-water species. This distinction will not hold; for at Cedar City, Utah, one of the coal seams of the Laramie group contains and is overlain by sheets of fresh-water marl composed of shells of *Unio*, *Goniobasis*, *Physa*, *Paludina*, etc., and above these is a stratum of calcareous sandstone containing *Inoceramus* and a bed of oyster shells four feet in thickness.

Professor E. D. Cope: I would like to ask what the geographical extent of the Fort Union beds may be?

Dr. Newberry: I do not think that question can be answered fully, because there is a large area in Wyoming and Montana which has not yet been explored. The southern limit of the Fort Union group and its contact with the Laramie may perhaps be found in that section. In Colorado I have never seen any Fort Union strata. They extend far into the Canadian territory, as they have been recognized in many localities by the Canadian geologists, and have been called the "Porcupine Hills" or "Paskapoo" series. In Mr. Tyrrell's report for 1886 (on northern Alberta) you will find an interesting discussion of this question, and a list of the plants of the Paskapoo beds is given. They are all Fort Union species. The "Edmonton series" is apparently the representative of part of our Laramie.

Professor Angelo Heilprin: I would like to ask Professor Newberry whether, acccording to the interpretation which he has given, the Laramie, as a Cretaceous formation, disappears; and, if this is the case, I should like further to ask what horizon in the Cretaceous the Laramie represents—whether it is the equivalent of what has always been considered the uppermost Cretaceous or whether there is something imposed upon it? So far as I have seen, from the evidence that Professor Newberry submits, the link between the Cretaceous and the Tertiary totally disappears.

Dr. Newberry: In my judgment the Laramie is the top of the Cretaceous system. I do not know why it should be called post-Cretaceous. It is true there must be somewhere connecting links between the Cretaceous and Tertiary, as the streams of time and life have flowed on continuously and geological agents have been acting incessantly. So we shall ultimately find passage-beds bridging the interval between the Mesozoic and Cenozoic; but I know of no evidence that the Laramie is such a passage-bed. In the lower part it contains Fox Hills fossils, and thus is linked to the Colorado group, but if we separate it from the Fort Union group it has really no connecting links with the Tertiary.

The physical history of the Cretaceous system in the interior of the continent is

briefly as follows: In the region now bordering the Gulf of Mexico on the south and west during the first half of the Cretaceous age marine conditions prevailed, and in the sea of that time and place several thousand feet of limestone were deposited—the Comanche group of R. T. Hill and Dr. White. Most of our continent was out of water during the long interval measured by the deposition of the Comanche limestones, but about the middle of the Cretaceous age the sea rose over its shores and submerged all the great depressed area between the Alleghany and Canadian highlands on the east and the Rocky Mountains and Wasatch on the west. When the sea invaded this area its shore waves spread a sheet of sea beach, the Dakota sandstone series, as far as the submergence extended. As the water deepened over the area of the plains, marine sediments were laid down on the Dakota; in the open sea, limestones 2,000 feet or more thick—the Fort Benton, Niobrara, Fort Pierre, and Fox Hills groups of Meek and Hayden. Near the western shore of the Cretaceous sea the sediments were more earthy, shales alternating with concretions and continuous beds of limestone, and in places 2,000 feet or more of bituminous shale. In the mountains of New Mexico, Colorado, and Wyoming the divisions of Meek and Hayden's upper Missouri section cannot be identified, and so Mr. Clarence King called the strata immediately above the Dakota the Colorado group. At the top of this we find a sudden change of sediments, sandstone and shales with beds of coal succeeding the bituminous shales and limestones. This is the Laramie. There is no unconformity here except what may be due to erosion and such as we always or often find where strata of coarse materials, sandstones and conglomerates that have been deposited by rapid currents, rest upon fine and quiet-water sediments. The Laramie is tied to the Fox Hills by some of its fossils, and the heavy sandstone which lies at its base in southern Colorado and New Mexico has been called by Professor Stevenson the Fox Hills sandstone, but it seems to me better to begin the Laramie with the change of sediments rather than attempt to maintain the identity of the Fox Hills group in this region. The epoch of the Laramie was one of disturbance, at least of local oscillation of water level. The sandstones are shore deposits, the shales shallow water sediments, and the numerous coal beds were formed under subaërial conditions, and they are remarkably local. Sections quite near each other show great differences in the number, relative position, and thickness of the coal seams. This means frequent and local changes of level. The coal seams give the Laramie group greater economic importance than any other formation in the middle and western parts of the continent. It is generally coal-bearing, and its coals are in some places of remarkable thickness and purity. Probably no equal area in the world rivals, in the quantity and quality of its coal, portions of the Laramie of western Colorado.

Mr. J. B. Tyrrell: We find what we have called the Laramie and have correlated with the Fort Union group, lying directly on the Fox Hills beds, the beds from which the plants are largely obtained. I have collected large numbers of them myself. Between those plant beds and the typical Fox Hills beds there is a series, lying perfectly conformable to both, of white sands and clays that hold the most of our western coal deposits, and which have been discriminated in the reports of the Geological Survey of Canada. The three series in Canada are perfectly conformable. There is no break whatever between the Colorado group and the top of the Laramie, and there is a thickness of five to six thousand feet to the top of the Fort Union group with no break at all in superposition; there has been a regular sequence from the bottom to the top. So if the Laramie comes in anywhere it must come in at the bottom, and it appears to me that it must come in there and not in the upper beds.

We cannot clearly recognize the American divisions; but if the top of our beds represents the Fort Union, the Fort Pierre beds are six hundred feet below. I suppose, then, that we would have to regard the intermediate shales and sandstones as Laramie, though there is little to show why they should be separated from the Fort Union group above.

Professor LESTER F. WARD: I take it that the discussion here to-day should avoid, so far as possible, repetition of the statements that have already been published. Like Dr. Newberry, I have in my hands a large amount of material both from the typical Laramie group and from the Fort Union group, which has not been published. A few years ago, as you all probably know, I did publish a paper on the Laramie group, to which I prefixed a prefatory discussion in regard to the probable age of that group. In that discussion I admitted that there was the same lack of identity between the Fort Union fossil plants and those of the lower Laramie which Dr. Newberry has pointed out. In further investigations of this material (for at that time I had only studied a small portion of it, except in a very general way) I have not had any occasion to alter my opinion in that respect, and I am to-day prepared to say what I said then and what Dr. Newberry has said this morning, viz., that so far as the floras of the Fort Union group and of that which was originally called the Laramie beds of Colorado, Wyoming, and New Mexico are concerned, they are not identical—they are very different.

I hazarded a possible explanation in case the geologists and animal paleontologists eventually establish the synchrony of those beds, viz., that possibly the latitude taken in connection with a different topography such as may have existed in the two regions might account for the great difference in the floras. But I also expressed the opinion that in all probability there would eventually be found a difference of age—how great it would be premature for me to say. The great difference is not so much in the species as in the general facies of the two floras. There are eight or ten identical species* in the Laramie and Fort Union, but these weigh very little in comparison with the more important fact that in the lower Laramie—the original Laramie formation—there is a large predominance of such genera as *Ficus*, and also many palms, which, to the mind of a paleobotanist naturally and probably correctly suggests a warmer climate.

Whatever may be true in regard to the difference of age—and it seems to me that the two must go together—I am quite satisfied that a warmer climate prevailed during the period of the deposition of the Wyoming and Colorado beds than that which prevailed during the deposition of the Fort Union beds. Among the leading genera of the upper beds are *Populus* and *Platanus*. Some of these forms are, I admit, very irregular and peculiar, but they are not found in any such abundance in the lower beds. They are more northern forms—forms which now, at least, grow in the colder climates, and very few species of *Ficus*, very few genera of palms, are found, so far as my own collection is concerned, in the Fort Union beds. Moreover, as Dr. Newberry has stated,

*The species common to the Laramie of Colorado and Wyoming and the Fort Union group, as shown in the table of distribution given in my Synopsis of the Flora of the Laramie Group (Sixth Annual Report U. S. Geol. Survey, 1885, pp. 443-514), are as follows:

Sequoia langsdorfii,
Sabal campbellii,
Quercus olafseni,
Juglans rhamnoides,
Juglans rugosa,
Ficus tiliæfolia,
Magnolia hilgardiana,
Trapa microphylla.

These are exclusive of several species thus far only found in the Laramie of British Columbia and one of the American areas, as also of a number of more or less doubtful cases.

there are forms in the Fort Union which have an exceedingly recent facies, but I am very loath to argue from this a Tertiary age. For instance, there are what seem to be the leaves of the identical species of hazel which grows now in the eastern parts of the United States; yet I hesitate to argue from this that the formation is necessarily very recent.

In fact, the material from the Fort Union formation which is still in my hands (partly for the reason that I was unable to identify it with the published flora of the globe, and partly because I was unable to publish more at that time) inclines me to believe that there would really be, as I then stated, no inconsistency in assigning to the Fort Union an age as ancient as the closing period of the Cretaceous system. Some of the facts I might enumerate here, but this would be perhaps tedious; but some of the forms are certainly not to be identified with any of the genera that have been found in the fossil or the living state. Such forms cannot be regarded as having geological importance in fixing age, yet they go a long way in the direction of showing us that the age may be more ancient than has been supposed. The genus *Trapa* has been found in both groups, but I am not thoroughly satisfied that the species are identical. In my anxiety not to multiply species, I called it by the name given to the form described by Lesquereux from the Point of Rocks beds, though it may prove to be a distinct species; yet we may never know, from the fact that the material collected by him was inadequate. I have collected from the Fort Union beds specimens of that plant containing entire rosettes of leaves as they would lie on the surface of the water, and showing to my mind that it must have belonged to the genus *Trapa* or a closely related form. The Point of Rocks material contained nothing but isolated leaves—that is to say, there were no rosettes and there were no stems—simply the form and nervation of the leaves. These point to the genus *Trapa*, and the probability is that they belong to that genus.

The evidence afforded by the beds at Black Butte station, where the great saurian was discovered by Professor Cope, is perfectly conclusive of the identity of the age of the beds from which that fossil was taken with that from which the leaves of that particular locality were taken. We have at the National Museum a specimen of the bone from that creature, adhering to the opposite side of which is one of the characteristic Laramie leaves. I have been on this spot, and collected other fossil plants from the same immediate locality.

Now, with regard to the error, if error there be, in harmonizing or identifying the Laramie and Fort Union deposits: I suppose the responsibility for this must largely rest upon Dr. White, who has made a very thorough and exhaustive study of the entire region, as he defines it from the standpoint of its molluscan fauna; and it seems to me that his identification of the two groups—and I have conversed with him very freely and very much upon this subject, and what I say is from memory of the oral statements made by him—was in the nature of a broad, geological generalization. He, in his extensive labors in that field, simply came upon the salient fact, that throughout the larger part of the region now occupied by the Rocky Mountains there is abundant evidence that there existed at a remote period, somewhere near the close of the Cretaceous or beginning of the Tertiary period, a great land-locked sea, originally somewhat salt, later brackish, and finally nearly fresh; and that the deposits which were made at the bottom of the sea are apparently continuous all the way up from the pure marine deposits of the upper Fox Hills group to the highest of the Fort Union deposits; and he even ventures to say he has traced it in some places still higher into strata which are admitted to be Tertiary.

I have one fact of my own observations which may be worth stating and which may not be known to all. About 15 miles above the town of Glendive, on the right bank of the lower Yellowstone river, there is a cliff, known as Iron bluff, which is colored very bright red from having the carbonaceous matter burned out, and which is full of fossil plants. It is also full of the characteristic Laramie shells, such as Dr. White has described and has daily met with throughout the Laramie series. These shells, he informs me, are identical all the way through the Laramie from bottom to top. There is nothing to indicate that there is any difference in the age, so far as the indication from the shells is concerned. This bluff is right on the bank of the Yellowstone river, and the railroad cuts through it, which makes the cliff there conspicuous. Immediately below there is a short anticline, apparently a little island about a mile in extent, filled with characteristic Fox Hills Cretaceous fossils. I have been on the ground and collected large numbers of them, and everywhere we meet with them: the wheels of the wagon as one drives over them crush the shells, so abundant are they; and there is no doubt that this is a typical Fox Hills bed, in Dr. White's understanding of the term "Fox Hills." Now, so far as I can tell, and so far as he could tell from a careful study of the ground, this Iron bluff deposit—this Laramie or Fort Union leaf-bed—rests directly and immediately upon the Fox Hills bed. If there is any difference of age there is no indication at that point that it has been wanting from lack of conformity or from any other cause; and it is certainly a very natural conclusion that when one deposit rests conformably upon another at one point, and when at another point two formations, the lower one being the same as in the first case, have the same order and arrangement, the age of the overlying beds in both regions is the same. That seems to be as clear a case of geological reasoning as we have.

I observe that our friends across the border, of whom we have representatives here, are still using the term Laramie for this formation. It seems to me that the bulk of their Laramie is nothing more nor less than our Fort Union, and they seem to be somewhat in doubt (at least so I learn from reading a paper which reached me only a day or two before I left Washington, with a Christmas greeting from Sir William Dawson); and I do not know but that we might as well settle the question in the way he has settled it in that paper as in any other way. He simply says that the time may yet come when, in fixing our arbitrary position for the line between the Cretaceous and the Tertiary, we may be obliged to draw it through that continuous deposit which we call the Laramie group.

Dr. Newberry's memory is entirely at fault when he says that in my "Synopsis" I called the Laramie and Fort Union group Tertiary. I have been criticised for arguing that they are Cretaceous. As a matter of fact I did not call them the one or the other or argue for either view. I first gave a perfectly unbiased review of opinion in which the advocates of each view were allowed to state their case in their own words. I then did what had never before been done. I presented the evidence from the fossil plants upon both sides in tabular form, getting together for the first time a fairly complete list of all the upper Cretaceous species the existence of which had generally been ignored in the discussion of the question. These as well as the Eocene species of all parts of the world were directly compared with the Laramie species. The very careful analysis of this table which I made showed that the Laramie flora occupies an intermediate place between that of the upper Cretaceous (above the Dakota group and Cenomanian) and that of the Eocene. The only conclusion I drew,

if conclusion it can be called, was that the whole discussion was a war of words, often unworthy of the talent that had been expended upon it.

Professor J. J. STEVENSON: I should like to say a word or two about the section that Dr. Newberry has put on the board. The statement that the Colorado group cannot be differentiated in Colorado is not altogether correct. It is true that in a considerable area beyond the Arkansas range it is a very difficult thing indeed to differentiate the Colorado group; but along the plain in front of the Rocky Mountains in Colorado and New Mexico there is not the slightest difficulty in recognizing the Fort Benton as a mass of black shale; the Niobrara above that, gray to blue limestones separated by black shale; then the Fort Pierre, drab to yellow sandy shales, containing nodules of limestone and iron ore, while above that and quite easily separable from it we find in northern and central Colorado the Fox Hills group. This is the Cretaceous along the waters of the South Platte, where the Fox Hills group is characterized all the way, from the bottom to the top, by a nodose fucoid, *Halymenites major*, which was at one time a very interesting topic of discussion. The Fox Hills group in central Colorado is upwards of one thousand feet thick, consisting mostly of sandstones, some of them calcareous and rich in Fox Hills fossils, with some beds of coal, which have been opened in the neighborhood of Greeley. At Cañon City, Colorado, the Fox Hills group is only about 350 feet thick, that being the vertical extent of the *Halymenites*. In that interval are the important coal beds and numerous sandstones or shales containing plants which doubtless answer to those of the plant bed which I found on one occasion near Evans, on the South Platte, but which I could never find again. Further southward, near Trinidad, Colorado, the Fox Hills is only 80 feet thick, that being the vertical range of the *Halymenites*. In that field, however, the Fox Hills has been included in the Laramie; but the Laramie group above the great coal-bearing series is easily separable from this *Halymenites* sandstone. Southward, in New Mexico, the *Halymenites* or Fox Hills sandstone entirely disappears.

The point I wish to make is that the upper Missouri section of the Cretaceous is distinctly recognizable as far south as central Colorado. Beyond that southward the Fox Hills thins out until it disappears in New Mexico, but the other members of the section can be recognized without any difficulty in front of the Rocky Mountains and around their southern end to the Rio Grande.

Professor E. D. COPE: It seems to become more complicated the more we investigate, and a greater number of problems arise to be solved. What Professor Stevenson has just given is established. I can demonstrate from my own observation what Dr. Hayden has stated—that is, the conformity of the four or five gradations with the Laramie above. There seems to be absolutely no disturbance or want of conformity in the upper Missouri between those three horizons. I could get the Pierre fossils in the bottom of the bluff and Fox Hills in the middle and Laramie at the top. On the question of the Laramie's position in the Cretaceous or Tertiary series the vertebrate fossils throw some light. The reptiles and saurains are Cretaceous. I have discovered in New Mexico the Puerco series just above the Laramie, and in that I have about a hundred species of the mammalia. I have also discovered mammalia in the Laramie. Professor Marsh has added some species to those previously known. These species are of identical character with the Puerco mammals, although there is no species identical with any in the Puerco, where there is not a single Cretaceous reptile. The mammals of the Laramie are, like the saurians, rather Cretaceous than Tertiary; but the character is not so pronounced.

The next paper read was on—

OROGRAPHIC MOVEMENTS IN THE ROCKY MOUNTAINS.

BY S. F. EMMONS.

The paper was briefly disoussed by J. S. Newberry and J. W. Spencer. It is published in full among the memoirs, forming pages 245–286 of this volume.

The next communication was the following:

NOTE ON THE ERUPTIVE ORIGIN OF THE SYRACUSE SERPENTINE.

BY GEORGE H. WILLIAMS.

The undisturbed Paleozoic strata of New York state are so noticeably free from intrusions of igneous rocks that any occurrence whose eruptive nature can be established possesses an unusual interest. Such an occurrence is the serpentine of James street hill, in Syracuse, the real nature and origin of which has only recently been placed beyond all doubt by new exposures made in the course of street grading.

This rock has been known since 1837. It was described by Vanuxem and Beck in the New York state reports, who regarded it as "metamorphic," but as probably not produced by igneous action. Hunt has lately brought the occurrence again into prominence by citing it at great length in his "Mineral Physiology and Physiography" as evidence for the origin of serpentine by chemical precipitation from aqueous solutions.

The rapid growth of the city had apparently rendered the serpentine permanently inaccessible when, in the winter of 1886-'7, the writer succeeded in obtaining for study a considerable series of specimens preserved in old collections. The results of this purely petrographical examination (communicated to the National Academy of Sciences April 20th, 1887, and published in the American Journal of Science for August of the same year) were (1) the identification of the Syracuse serpentine, in spite of its advanced state of alteration, as a member of the rare peridotite type, kimberlite, similar to those described by Lewis from South Africa and by Diller from Kentucky; and (2) adducing from the structure of the rock strong evidence of its eruptive origin.

This evidence has been set forth at length in the above-mentioned paper, and need not be again referred to here. The object of the present communication is to make known certain new and unexpectedly acquired evidence, which places the igneous origin of the Syracuse serpentine beyond a question.

Since 1887 the digging of a deep sewer on James street and the lowering of the grade of Green street, about forty rods further south, have exposed two admirable sections through the serpentine, which disclosed its relations to the adjacent limestone and at the same time yielded an abundance of material for further study. These exposures established three distinct proofs of eruptive origin for the serpentine in addition to the internal evidence already adduced from the structure of the rock itself. These three proofs are as follows:

1. *The mode of occurrence of the serpentine in the limestone.*—This was distinctly that of a dike, cutting perpendicularly across the nearly horizontal strata; forcing

its way in places between them; and, as seen in the exposure on Green street, considerably disturbing them in its immediate vicinity. Two sections, drawn with care to a large scale, show the serpentine in a position in the limestone difficult, if not impossible, to account for except on the hypothesis of eruptive origin.

2. *Inclusions brought up by the intrusive rock from below.*—Much of the serpentine is full of angular fragments of other rocks imbedded in it. Some polished specimens (exhibited to the Society) have at least one-third of their surface composed of such included fragments. The vast majority of these are composed of the adjacent limestone, but others also occur. One specimen contains a large fragment of black shale (probably Utica shale), which here is over 1,000 feet below the surface; another specimen contains a fragment of an acid crystalline rock, granite or gneiss, which must here lie over 2,000 feet below the surface. Vanuxem mentions such granitic and syenitic inclusions as not uncommon. They could not, however, have become imbedded in the serpentine except at a considerable depth, whence they were carried upward by the molten rock.

3. *The zonal alteration of angular limestone inclusions.*—As has been already mentioned and as is well shown by the specimens exhibited, the Syracuse serpentine is frequently full of limestone fragments, which differ much in shape and size. All of these included fragments show the effects of contact metamorphism through the influence of heat, and the new minerals which are produced in this way have invariably a zonal arrangement parallel to the sides of the fragments. This is a proof that the metamorphism could only have been effected after the limestone had been broken into its present shape and imbedded in the serpentine; hence the enclosing rock must have been the agent of metamorphism.

In speaking of the eruptive origin of the Syracuse serpentine it is not, of course, intended to imply that the original eruptive rock was itself serpentine. Serpentine, as is well known, is always an alteration product of some other rock—generally of a feldspar, free basic eruptive, or peridotite. The Syracuse rock is not now by any means all serpentine, although a greater portion of it has been changed by hydration into this mineral. Nevertheless, enough of the minerals and structure of the original rock still remain to identify it with the particular type of peridotite known as kimberlite.

There is another occurrence of serpentine, with mica crystals one-third of an inch broad, mentioned by Vanuxem at a fault between the Calciferous and Utica, near Manheim bridge, on East Canada creek, New York. It is associated with crystalline carbonate of lime containing pyrite and blende.*

The President, Professor JAMES HALL: There is a dike of trap rock, also mentioned by Vanuxem, cutting the Genesee slates near Ludlowville, New York.†

Mr. J. F. KEMP: There are a number of such occurrences near Ithaca. There are small cracks in the Devonian shale that very strongly resemble dikes. In these the material seems to be shale, and is in such an advanced stage of alteration that it readily effervesces with acids. The rock is at least extraordinary, containing as it does abundant *biotite*. It has a high specific gravity. The largest dike is not more than two or three inches wide where it cuts the shale.

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* N. Y. State Geological Reports, Vol. III, 1842, p. 207.
† Ibid., p. 169.

The next paper was entitled—

NOTES ON THE SURFACE GEOLOGY OF ALASKA.

BY ISRAEL C. RUSSELL.

This communication was discussed by N. S. Shaler, T. C. Chamberlin, and Mr. Russell. It is published, with the discussion, among the memoirs, forming pages 99–162 and plate 2 of this volume.

At the close of the discussion the Society adjourned to meet in the same place at 10 a. m., December 27.

Session of Friday, December 27.

The Society met at 10 a. m.; President Hall in the chair.

The report of the Council was read, as follows:

REPORT OF THE COUNCIL.

To the Fellows of the Geological Society of America.

The Executive Council present the following report:

The number of Fellows now on the roll is 173, three having died since the last meeting of the Society. The canvass of ballots cast for Fellows shows an addition of fifteen to the number; so that the Society will begin the new year with a roll of 188 Fellows. The Treasurer reports a balance of $1,716 in the treasury.

After mature consideration, the Executive Council have determined upon a plan of publication which differs not materially from that proposed in the admirable report * of the advisory committee appointed at the Ithaca meeting. For the present, there will be but one series, a large octavo, to be known as the "Bulletin of the Geological Society of America." All abstracts of papers with the accompanying discussions, as well as the briefer papers, will be published in the Proceedings of the meetings; the longer papers and the discussions upon them will be published separately from the Proceedings, but authors will not be required to receive the discussions with their separates. A contract on favorable terms has been made with Messrs. Judd & Detweiler, of Washington, D. C., for the publication of the material already on hand, and the manuscript for the most part has gone forward to the printers. Publication will be pushed promptly from this time, as all preliminary matters have been settled.

The whole matter of publication has been placed under the control of the Executive Council; but the conditions should be well understood by Fellows. The income of the Society for 1890 is likely to be not far from $1,900.

* Copies of this report were distributed at the Toronto meeting.

The expenses of administration will probably be about the same as in 1889; the Bulletin will average, with cost of covers and of distribution, somewhat more than $2.00 a page for the edition of 500 copies; there is every reason to look for almost 600 pages of text. The margin, therefore, is not more than $400. This admits of but limited expenditures for maps, cuts, and plates. It is evident that the Fellows must exert themselves to place the publications on a sure basis by securing a fund for defraying cost of proper illustrations.

The presentation of estimates of expenditure for the year 1890 cannot be made satisfactorily, as the Society has only begun its effective work; but there is necessity that authority for expenditures in publication be given to the Executive Council at this meeting. The estimate for printing the Bulletin is based on the agreement with Messrs. Judd & Detweiler, according to which the cost of the Bulletin, including paper and everything else, excepting the covers and binding, will be $1.90 per long primer page and $2.20 per brevier page, the former being used for memoirs and the latter for other matter. The expenses of the Secretary for postage, stationary, and printing will probably fall below those for 1889.

The canvass of the ballots received by the Secretary shows that the Constitution recommended by the Committee appointed at the Ithaca meeting has received the requisite three-fourths vote in favor of its adoption, so that that Constitution, with the accompanying By-Laws, will go into effect immediately upon the final adjournment of this meeting.

The new Constitution provides that vacancies arising shall be filled by the Council *ad interim*. This involves the selection of three additional Councilors, and also, if the Council think it necessary, an Editor. The Council is of the opinion that the selection of an Editor is indispensable.

The Executive Council cannot refrain from congratulating the Society upon the auspicious close of the first year. There have been manifested on all sides a sacrifice of personal feeling, a readiness to yield cherished opinions respecting methods, a freedom from self-assertion, and an earnest determination to make the Society succeed which could have been expected hardly by the most sanguine, and which augur well for the future of the Society.

The Executive Council present the following recommendations:

1. That the Treasurer be authorized to pay all bills for publication of the Bulletin, when they have been certified by the officers chosen by the Council.

2. That immediate efforts be made to secure a Publication Fund of $10,000, to provide an income to pay for maps, plates, and other illustrations such as ordinarily cannot be paid for by the Society.

3. That the Treasurer, with advice of the Council, be authorized to invest as the first part of the Publication Fund $1,000 of the money now in the Treasury.

4. That the Council be authorized to prepare a list of exchanges, not to exceed 75 in number.

5. That the Fellows pay strict attention to the section of the By-Laws providing for commutation of annual dues by a single prepayment of $100.

The recommendations of the report were adopted by vote of the Society.

The President then delivered an address on the early history of American geology and geologists, for which the Society, on motion of J. D. Dana, voted its thanks. Professor Dana followed with a few additional statements.

The first paper of the session was—

ORIGIN OF THE ROCK PRESSURE OF NATURAL GAS IN THE TRENTON LIMESTONE OF OHIO AND INDIANA.

BY EDWARD ORTON.

The paper was discussed by I. C. White, A. C. Lawson, W J McGee, and Professor Orton. It is published in full among the memoirs, pages 87–98.

The next paper was—

ON THE TERTIARY DEPOSITS OF THE CAPE FEAR RIVER REGION.

BY WILLIAM B. CLARK.

There is perhaps no portion of our country where the relations of the deposits are less clearly comprehended than in the Coastal Plain bordering the Atlantic. This region varies in width from a few miles in the north to more than one hundred and fifty miles in Georgia, and covers the eastern portions of New Jersey, Delaware, Maryland, Virginia, the Carolinas, and Georgia, together with all of Florida. Bounded upon the west by the hilly country of the Piedmont Plateau, it stretches away to the coast, an almost level area, except where broken by the meandering rivers and their tributaries, that have as yet but just entered upon their work of denudation.

To the various formations found represented within this region geologists have applied the taxonomic terms Cretaceous, Eocene, Miocene, etc., although from the meager study of the fossiliferous deposits that has hitherto been made we are by no means certain that these terms can be used with propriety. It is not the intention in this paper, however, to discuss this aspect of the subject, important as it is, for that can best follow a detailed examination of the stratigraphy and paleontology of the entire area.

The Cape Fear river region presents some of the most puzzling problems in the geology of the Coastal Plain. The formations here represented have been often referred to in geological literature, and quite different opinions held as to their correlation. In its topography the Cape Fear river region partakes of the general character of the Coastal Plain, which limits the study of the pre-Quaternary strata mainly to the river banks and accidental excavations.

There has apparently been little difference of opinion as to the taxonomic position of the greensand marl, that is widely characterized by the accepted Cretaceous fossil

Exogyra costata. Starting with this horizon, which forms the base of the series in the lower Cape Fear river region and is the most extensively represented of any of the fossiliferous deposits, we find that in several localities it is overlain by a light-colored calcareous marl, that in the neighborhood of Wilmington occurs as a compact, fine-grained limestone or as a firmly cemented calcareous conglomerate. An examination of the region shows that this marl occupies wide basins or hollows within the Cretaceous. It may be considered as Eocene. Its paleontological characteristics will be referred to later. Widely extended over Eocene and Cretaceous alike is an incoherent shell marl that may be referred to the Miocene. This, in brief, is the order of superposition of the several formations with which we have to deal.

These sediments probably represent a succession of events somewhat as follows: At the close of the Cretaceous period, the deposits that had been accumulated were elevated above the sea for a sufficient length of time to allow the meandering streams from the mountainous regions to the west, together with local tributaries, to excavate shallow basins. It is, moreover, evident that this process could not have been continued sufficiently long to plane off or base-level the region, else the depressions themselves would have disappeared. When this land surface became depressed below the sea, the deposits of the Eocene, formed largely from the remains of marine animals, were strewn over an uneven sea-floor. When elevation had brought them above the level of the sea, denudation again began, bearing away the materials accumulated. The elevation could not have been great, but erosion on the other hand was long continued, until the surface of the region was approximately base-leveled. In this planing down of the land, the higher ridges of the Cretaceous were likewise removed, so that an almost level sea-floor was this time presented for the reception of the sands and shells of marine organisms which form the next formation, recognized as Miocene.

A geological map of the Cape Fear river basin would exhibit the Eocene in numerous detached areas, while the Miocene would be found in long bands along the watercourses, an arrangement of the deposits that would be anticipated after they had passed through the various cycles of change above recorded.

That these various formations present paleontological peculiarities was early perceived. From the fact that the limestone afforded fossils which were recognized as in part of Cretaceous age, it was referred to the upper Cretaceous, or by others held to be transitional in character between the Cretaceous and Eocene.

Lyell* stated in a communication to the Geological Society of London, made in 1842, that one of his chief reasons for examining the geology of the southern Atlantic states was "to ascertain whether any rocks containing fossils of a character intermediate between those of the Cretaceous and Eocene really exist." The result was that he found "no secondary fossils in those beds which have been called upper Secondary and supposed to constitute a link between the Cretaceous and Tertiary formations." Lyell collected from the limestone at Wilmington and Rocky Point, the localities most carefully examined by the writer. Although the facts presented may not affect Lyell's general conclusions, yet the occurrence of characteristic Cretaceous fossils at the same horizen with Eocene is beyond dispute.

Tuomey stated before the American Association for the Advancement of Science in 1848† that "well characterized Cretaceous forms" occur at Wilmington in the same beds with fossils that are "considered characteristic of the Eocene of the United

* Proc. Geol. Soc. of London, vol. 3, 1842, p. 735.
† Proc. Amer. Assoc. Adv. Sci., vol. 1, 1848, p. 33.

States." A list of species is added. In a later publication* the same position is taken, though explained on the ground of contemporaneous existence.

Conrad stated in 1865, concerning this locality, that "Eocene and Cretaceous fossils are there mingled in a breccia,"† and later that "the mixture of Secondary and Tertiary fossils in this breccia shows that a disturbance occurred in the bed of the Eocene ocean, which evidently, from Tuomey's account, extended into South Carolina." Conrad cited several instances in which Deshayes and others have shown similar occurrences in European strata; and although he did not enter more in detail into a description of the Wilmington locality, yet his opinion as to the commingling of Eocene and Cretaceous forms is clearly stated.

By a comparison of the specimens with well-known forms from Claiborne and other Eocene localities, the following species have have been identified:—

Aturia alabamiensis, Conrad,
Pseudoliva vetusta, Conrad,
Oliva alabamiensis, Conrad,
Conus gyratus, Conrad,
Emarginula eversa, Conrad,
Trochita trochiformis, Conrad,
Siliquaria vitis, Conrad,
Pecten membranosus, Morton,
Terebratulina lacryma, Morton,
Lunulites distans, Lonsdale,
Mortonia pileus-sinensis, Ravenel,
Sismondia plana, Conrad;

besides others of Eocene aspect, but of whose specific determination there is some doubt.

At the same time numerous Cretaceous fossils occur; as—

Baculites compressus, Say,
Nautilus dekayi, Morton,
Navicula uniopsis, Conrad,
Venilia conradi (?), Morton,
Cardium spillmani, Conrad,
Cucullæa antrosa, Morton,
Gyrodes abyssimus, Conrad,
Zenophora leprosus, Morton;

enough certainly to clearly indicate the presence of a Cretaceous fauna in a great variety of forms. It is less probable that these different species had a contemporaneous existence than that a mechanical commingling of the various forms took place during the deposition of Eocene sediments. With few exceptions, the specimens are casts; but, as both those from the Cretaceous and Eocene present similar states of preservation, it is probable that at the time the commingling took place the shells were still intact, and that subsequently they have both passed along similar lines of change.

Another interesting occurrence of a like nature is the presence of *Exogyra costata*

* Proc. Acad. Nat. Sci., Philadelphia, vol. 6, 1852, p. 193.
† Proc. Acad. Nat. Sci., Philadelphia, vol. 17, 1865, p. 72.

in Miocene strata surrounded by numerous characteristic Miocene fossils. This was referred to by Emmons in 1858.*

Such comminglings of different faunas are not unknown in other regions and from other formations; but the writer knows of no instance where the occurrence is so marked or where, from the great number of fossils, the evidence is so undoubted.

The Cape Fear river region presents many other problems of geological interest that require more extended study before judgment can be passed upon them. These, together with other questions connected with the early Tertiary of the Coastal Plain, the writer is now engaged in investigating.

The next paper read was entitled—

NOTE ON THE PRE-PALEOZOIC SURFACE OF THE ARCHEAN TERRANES OF CANADA.

BY ANDREW C. LAWSON.

The paper was discussed by J. W. Spencer. It is published among the memoirs, forming pages 163–174.

The next paper on the programme was—

STRUCTURE AND ORIGIN OF GLACIAL SAND PLAINS.

BY WILLIAM MORRIS DAVIS.

It was read by title, the author yielding his time in order that there might be more time for discussion. This paper is published among the memoirs, pages 195–202, plate 3.

The Society then took a short recess.

After recess, Vice-President A. Winchell occupied the chair. In the absence of the author, Mr. J. B. Tyrrell read the following paper:

GLACIAL FEATURES OF PARTS OF THE YUKON AND MACKENZIE BASINS.

BY R. G. MCCONNELL.

The following notes, which I have endeavored to make as brief as possible, on the more salient glacial features of parts of the Yukon and Mackenzie basins, were obtained while on a hasty geological reconnaissance in the north in the summers of 1887 and 1888. The route travelled on this occasion followed the main water-courses of the country. Starting from the mouth of Dease river, west of the Rocky Mountains, in lat. 60° N., the Liard was followed in its stormy course eastward through the Rockies to its junction with the Mackenzie in the low lands east of this range. From Fort Simpson, at the mouth of the Liard, I ascended the Mackenzie and its continuation, Slave river, to Fort Smith, and then, turning northward, descended Slave river

*Geology of North Carolina by E. Emmons, 1858, p. 530.

to Great Slave lake, coasted along this lake to its outlet, and then descended the Mackenzie river through its whole length to the head of its delta at the mouth of Peel river, lat. 67° 45′ N. From this point the Rocky Mountains, here about four thousand feet in height, were recrossed by the Peel river portage to the head waters of the Porcupine, and the latter followed westward, through its long ramparts, to its junction with the Yukon. Then bending again to the south, the Yukon was ascended to old Fort Selkirk, where connection was made with the line of exploration traversed in the previous summer by Dr. G. M. Dawson. Of the rivers mentioned, the Makcenzie only had been previously examined by a geologist, and that only in a cursory manner and before the subject of glaciation had received much attention.

We shall commence the descriptive journey at Great Slave lake. This lake is situated upon the western margin of the Archean axis, and had originally the form of a great cross, with one arm penetrating the crystalline schists, while two others stretched north and south along the junction of these with the newer sedimentaries, and the fourth extended itself over the flat-lying Devonian to the west. The southern arm has now completely disappeared, and its bed is filled with a great alluvial deposit of clays, false-bedded sands, and fine gravels, which have been brought down by Slave river and through which its tortuous channel now winds. Not satisfied with burying the southern arm, this river is now pushing its delta far out to sea, and threatens at no distant day to inflict a similar fate on the whole eastern portion of the lake. The time spent on Great Slave lake was not sufficient to enable me to form a theory as to its origin which would have much value, but its peculiar shape, the great depth of the Archean portion taken in connection with the comparatively low elevation of the country which surrounds it, and the precipitous cliffs which border the shores of this part in so many places, seem inexplicable by glacial agencies. It is possible, however, that the western portion, which is much shallower and has low, shelving shores, may have been excavated in part or altogether by a glacier forcing its way out of a previously formed basin to the east. No very distinct groovings or striæ were observed around the lake, but the hummocks of the *roches moutonnées* gneissic surface of the country in the vicinity of Fort Rae have their major axes generally orientated in a direction about S. 30° W., or diagonally across the great northern arm of the lake on which the fort is situated. Well defined glacial hummocks carved out of massive dolomites were observed in one place on the western arm running in a westerly direction, or almost parallel to the general course of this portion of the lake.

Great Slave lake, like the other great lakes to the south lying along the Archean boundary, affords proof in the terraces surrounding it of former higher levels of its waters. Fragments of two lines of terraces were noticed in a number of places around the western arm of the lake. The greatest elevation of these did not, however, exceed 30 feet above the present surface of the water.

Hay river, which enters great Slave lake near its western end and drains the country to the southwest, has evidently had a history somewhat similar to that of the Niagara; but it has not yet been thoroughly explored. In its lower part its valley is carved out of a soft shaly terrane holding Hamilton fossils. Fifty miles above its mouth a heavy band of cream-colored limestone overlying the shales crosses the river, and a striking change is at once observed in the aspect of the valley. As we advance, the valley contracts and becomes a gorge, so deep and narrow that its precipitous walls, buttressed below by an embankment of fallen fragments, almost appear to overhang the stream, while the river, reduced in width in some parts to 100 feet, dashes

along its bowlder-filled channel with bewildering impetuosity. At several points small side streams fling themselves over the brow of the unworn cliffs and curve gracefully down into the stream beneath. Six miles above its mouth the gorge is interrupted by a fall 50 feet in height, and a mile further up is closed completely by a fall of 100 feet. Above the falls the river has failed to produce more than a feeble impression on the hard limestone beds which floor the surrounding country, and loses its valley almost altogether.

The Hay river falls owe their origin to precisely the same cause as that which produces the famous falls at Niagara, viz., the superposition of hard limestone on soft shales, and the consequent undermining and destruction of the former effected by the rapid erosion and removal of the supporting beds. It is interesting to find that the rate of retrocession of the two falls, measured by the length of their gorges, has been almost precisely the same. The quantity of the work done by the two streams cannot, however, be regarded as much more than a coincidence, as the factors in the two cases are entirely different. The volume of water which falls over the precipice at Niagara is ten-fold greater than that carried by Hay river, while its erosive power is relatively less on account of its greater purity. Besides Hay river, a number of streams which join the Mackenzie from the south and southwest in the first 100 miles of its course are interrupted by falls and heavy rapids, all of which probably date from the glacial period.

Proceeding down the Mackenzie from Great Slave lake, alluvial clays are noticed for some miles, and then a bowlder clay, scarcely distinguishable in character from the same formation as developed in eastern Canada 3,000 miles distant, makes its appearance. It occurs here as a light yellowish, compact, arenaceous clay filled with rounded Archean bowlders and, as elsewhere, showing only faint signs of stratification. It is traceable in numerous exposures as far as the mouth of the Liard, which joins the Mackenzie 150 miles from its head.

The Liard which joins the Mackenzie from the west, affords an excellent cross-section of the glacial beds covering the country between the latter river and the mountains. These do not, however, present much variety. Heavy sections of bowlder clay resting on the Devonian limestones occur along the valley for the first 50 miles, and then sink beneath the surface; and in the next reach of 50 or 60 miles the river winds through one of those filled-up preglacial depressions which are so frequently met with on the area of the Great Plains. In this the ordinary lake deposits only are seen. West of this basin the Cretaceous shales, which have now replaced the Devonian limestones, rise to the surface but are capped with stratified shales, sands, and gravels only, the bowlder clay having disappeared. Glacial erratics, on the other hand, extend far beyond the limits of the bowlder clay itself, and are found in some abundance as far west as the eastern edge of the plateau country, which in this latitude borders the foothills of the Rocky Mountains. They were also found on the flanks of a mountains ituated opposite Fort Liard, in lat. 60° 15′ N., long. 123° W., at a height of 1,500 feet above the surface of the surrounding country, or about 2,300 feet above the sea.

Returning to the Mackenzie and continuing on our way down it, we find bowlder clay resting on the surface of the rocks and filling up irregularities in the old preglacial surface as far north as the head of its delta in latitude 67° 45′ N., and this notwithstanding the fact that less than 100 miles below the mouth of the Liard the Mackenzie enters the flanking ranges of the Rocky Mountains; and for the next 500 or 600 miles its valley is partially guarded on the east by ranges of mountains, some of which ex-

ceed 4,000 feet in height. The bowlder clay or till of the Mackenzie valley, although mostly of the ordinary type, presents some variations. For many miles above Bear river it is exceedingly dark in color and, with the exception of one layer at its base, is almost destitute of bowlders. It has a thickness here of over 250 feet. In other places it exhibits an imperfect stratification, and it frequently holds irregular shaped inclusions of a lead-gray clay, some of which are distinctly bedded.

The only evidence of an interglacial period observed was the discovery in one place of an intercalation of stratified sands and gravels dividing the bowlder clay into upper and lower parts. This might, however, be due to a purely local cause.

The bowlder clay throughout the greater part of the valley is overlain by heavy deposits of stratified sands, clays, and gravels, and is underlain by a gravel formation somewhat similar to that which occurs in the same relative position on the plains of Alberta and Assiniboia, and which I have elsewhere called the Saskatchewan gravels; from which, however, it differs in containing a larger proportion of Laurentian pebbles.

The few facts observed in regard to the direction of the ice flow in the Mackenzie valley support the theory of Dr. Dawson as to its northerly movement. In the western part of Great Slave lake the direction of the ice current, as previously stated, was due west. Five degrees further north, well marked glacial striæ trending N. 15° W. were found crossing the summit of Roche Carcajou. This rock, which must have been completely submerged, rises to a height of 1,000 feet above the surface of the river. Important evidence on the same point is also afforded by the fact that the till near the lower ramparts of the Mackenzie is in approximately the same latitude as the northern boundary of the Archean area to the east, and the gneissic bowlders which it contains must have travelled either directly west or northwest in order to reach their present situation.

The facts adduced above allow the inference that the ice from the Archean gathering grounds to the east poured westward through the gaps and passes in the eastern flanking ranges of the Rocky Mountains until it reached the barrier formed by the main axial range, when, being unable to pass this, it was deflected to the northwest in a stream from 1,500 to 2,000 feet deep down the valley of the Mackenzie and thence out to sea.

Leaving the Mackenzie for the Yukon, we climb and cross over a couple of terraces, the higher of which has an elevation of 500 feet above the river or about 600 feet above the sea, and then on this route leave all traces of the glacial age behind, although a few miles further north erratics are found fully 1,000 feet higher. In descending the mountains on the west we follow a branch of Rat river through a wild cañon cut out of flat-lying sandstones and quartzites, from the mouth of which a level terrace, with fragments of a higher one resting on it in places, stretches west to Rat river. These terraces are much higher than those on the eastern side, and have an elevation of 1,500 to 1,700 feet above the sea. Proceeding down Rat river to the Porcupine, and down the latter through its ramparts, sands, gravels, and silts are found resting on the country rocks, but no bowlder clay nor glacial erratics were anywhere seen. Some distance below the ramparts the valley of the Porcupine widens, and from that on to its mouth it serpentines through a low alluvial plain elevated only a few feet above the surface of the river and evidently representing a filled-up lake basin or former wide dilatation of the river channel. Turning up the Yukon from the mouth of the Porcupine, this river splits up into innumerable channels and, spreading out in places to a width of eight or ten miles, cuts for 75 miles through the same alluvial formation. Above this the valley becomes more contracted,

gravels similar to those on the
... wide gravel terraces from
... the way to the Kink rapids.
... seen since
... grooves and
... are everywhere evident.
... the Yukon ...
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... attention ... fact which may have
... Alaska and the adjacent ...
... glaciers are unknown ...
... Athabasca ...
... summer in sheltered nooks. ...
... altitudes ... in the Peel river ...
... disappeared ... before the middle of ...
... no snow was seen until
... this stream were ...
... extend the present glaciers
... have little or no effect in
... northern ...

... continuation of the discussion on Alaska,
... Russell, J. W. Spencer,

... AND THE ADJOINING TERRITORIES
... CANADA.

... discussed by ... Mills, T. C. Chamberlin, N.
... J. W. Spencer and Mr Tyrrell. It is published
... pages 205 ... of this volume.
... paper, read by Professor C. H. Hitchcock in
... is contained in the following abstract:

... OF ... IN ONTARIO.

BY ... FREDERICK WRIGHT.

[Abstract.]

... occupied with the results of an investigation as to the
... in Whitchurch and King townships, York county, On-

tario. Oak Knolls is the name of a part of the continuous ridge separating Lake Ontario from Lake Huron. The height of this ridge above tide does not vary much from one thousand feet, as shown by the railway elevations. At King station, on the Northern railway, the elevation is 955; but this is not the highest point of the road, and the glacial summits rise on either side considerably higher. At Goodwood, on the Midland division of the Grand Trunk, it is 1,090 feet. At Pontypool, on the Canadian Pacific railway, fifty-two miles northeast of Toronto, the elevation is 1,064 feet. At Summit station, fourteen miles north of Port Hope, the elevation is 910 feet. Whether this is the highest point or not I do not know, nor have I the facts concerning the farther extension to the east. West of the meridian of Toronto this dividing ridge is continuous and still higher to the vicinity of Lake Huron. Here its height is doubtless occasioned by the general elevation of the older geological strata. Extensive deposits of gravel, however, are described by the Canadian geologists as extending along its northern slope to Collingwood and Owen sound (see Geology of Canada, 1863, pp. 908, 909).

In the section which I specially studied in York county the features were in every respect those characteristic of a terminal moraine, corresponding as closely as is possible to the features presented on Cape Cod and in the kettle moraine of Wisconsin and the coteaus of Dakota. Through the south part of the township of Whitchurch it consists of a line of massive knolls and ridges of unmodified drift enclosing numerous kettle-holes and lakelets, forming the watershed between Lake Simcoe and Lake Ontario. On the northern slope it is bordered at very near the summit level with extensive deposits of stratified sand and gravel. Still farther to the north the land descends rather rapidly to the level of Lake Simcoe—that is, to about the 600-foot level. Lake Simcoe would thus appear to occupy a vast space which was filled with ice during the time that these Oak Knolls were accumulating as a terminal moraine.

The explanation suggested to me while on the ground, and later when coming up from Lake Simcoe past Holland Landing and Newmarket to King station on the Northern railway, was as follows: In the recession of the ice-sheet, when it had reached the line of the Oak Knolls extending east and west from the vicinity of Kingston to Lake Huron, it remained stationary long enough for the accumulation of a vast terminal moraine which was high enough and solid enough to serve as a barrier to the outflowing waters which accumulated behind it in the further recession of the ice. Thus these stratified sands and gravels upon the north side of the Oak Knolls mark the margin of a glacial lake whose drainage worked off to the east somewhere in the vicinity of Kingston, and I should expect that a minute examination of the country would show evidences of this. Probably, however, this ridge existed as a long island, projecting above the surface of that great glacial lake which Professor Claypole has denominated Lake Erie-Ontario, and whose outlet was through the pass at Fort Wayne, Ind., into the Wabash river. But the melting of the ice in the rear of the moraine would cause currents to pass around in front of the ice eastward along the northern margin of the moraine, and thus account for the special deposits of sand and gravel there to be observed.

As obviating some objections to this theory, it should be borne in mind that in estimating the extent and continuity of the obstruction furnished by this moraine, we are not limited to the deposits as they now exist. While a moraine is forming, vast masses of ice are covered up by the débris, and, thus protected, may remain for a long while to add to the apparent height of the deposit and to serve as important elements in the obstructive barriers presented.

Professor J. W. SPENCER: I am very familiar with the region visited by Professor Wright. The deposits referred to were described by the Geological Survey of Canada many years ago, and more recently I have systematically traversed most portions of Ontario. If I understand correctly the epitome given by Professor Hitchcock, the Pleistocene deposits southward of Owen sound, called by the Canadian survey the Artemisia gravel, are regarded by Professor Wright as of one and the same series with those of the zone parallel to the north shore of Lake Ontario. But the deposits of the two localities are not identical. Those in the peninsula between the three great lakes—Ontario, Erie, and Huron—radiate more or less in all directions, and occupy the highest land in the country, ranging from 1,700 feet above the sea downward. The deposits are made up of three series of till, of gravels of kame and osar structure, and of beach formations. The ridges north of Lake Ontario, called by the names of Oak Hills, Oak Knolls, etc., have a general trend parallel to the lake for over a hundred miles, and have a maximum altitude of less than 1,200 feet. The Artemisia gravels are not found with these drift deposits. On the ridges, at elevations above the beaches of the Ontario basin, there are but few gravel deposits, for the country is generally too low for the formation of high-level beaches, which are embraced in the Artemisia gravels of the higher lands of western Ontario.

The next paper on the programme was read by the author. It is represented by the following abstract:

THE SOUTHERN EXTENSION OF THE APPOMATTOX FORMATION.*

BY W J MCGEE.

[*Abstract.*]

In a paper entitled "Three Formations of the Middle Atlantic Slope," published in the American Journal of Science early in 1888,† a distinctive late Tertiary formation, well displayed on the Appomattox river in eastern Virginia, was defined and named after that river, and its principal characters, its distribution, its stratigraphic relations, and its probable age were briefly recorded. The formation was then known to consist of a series of predominantly orange-colored non-fossiliferous sands and clays, resting unconformably upon Miocene and older formations, and unconformably overlain by the Columbia formation; it was known to expand southward from a thin and discontinuous bed exposed in a narrow belt on the Rappahannock river so rapidly as to form a terrane many miles in width on the Roanoke; and it was inferred to represent at least a part of the "Orange Sand" of Hilgard and other southern geologists.

Recent researches have shown that the formation extends and expands southward from the Roanoke river so as to constitute the most extensive and conspicuous terrane of the southern Coastal Plain on both Atlantic and Gulf slopes. The materials of the formation undergo some change in the Carolinas: the element of pebbles is less conspicuous over the uplands and more conspicuous along the rivers than in the middle Atlantic slope; where the formation rests directly upon or closely approaches the crystalline terrane, and in some cases where it rests directly upon the Potomac, considerable quantities of arkose enter into its composition; but the most notable change

* Printed in full in the Am. Jour. Sci. for July, 1890, 3d series, vol. xl, pp. 15–41.
† 3d series, vol. xxxv, pp. 120–43, 328–30, 367–88, 448–66.

is in the direction of more complete admixture of the sand and clay elements in the form of a moderately homogeneous loam. Still further southward the same characters are generally maintained, although in central South Carolina and in some other localities the hue of the formation is exceptionally rich and dark. Local variations also occur at different points in Georgia, Alabama, and Mississippi; and these may invariably and certainly be assigned to the influence of contiguous formations or other local conditions. So the Appomattox formation, as now known, may briefly be described as a series of obscurely stratified and frequently cross-bedded loams, clays and sands of prevailing orange hues with local accumulations of gravel about waterways, the materials varying somewhat from place to place and always in the direction of community of material between the formation and the older deposit upon which it lies; while as a whole the deposit retains so distinctive and strongly individualized characteristics as to be readily recognizable wherever seen.

The formation has been actually observed in thousands of exposures within a zone of fully 50,000 square miles, commencing a few miles north of the Rappahannock at Fredericksburg and extending southwestward between the Piedmont fall-line and the inland margin of the Coast Sands (a phase of the Columbia formation) through the Carolinas to central Georgia, and thence westward through Alabama and the greater part of Mississippi. If the direct observation be supplemented by legitimate and necessary inference, the formation must be so extended as to bridge the valleys from which it has been degraded, and to stretch beneath the various phases of the Columbia formation well toward the Atlantic and Gulf coasts; and with this legitimate extension the field of the formation becomes essentially coëxtensive with the Coastal Plain of the Atlantic and eastern Gulf slopes (exclusive of a part of Florida), and assumes an area of 250,000 or 300,000 square miles. The amount of erosion suffered by the formation in different parts of its area is significant, since in many cases it is evidently connected immediately with the local composition and remotely with the composition of the sub-terrane. Thus, the formation is generally preserved upon loamy and clayey belts, much more seriously invaded by erosion upon sandy terranes, and largely eroded from calcareous terranes.

In stratigraphic relation, the formation unconformably underlies the Pleistocene deposits (representing the southern extension of the Columbia formation), and unconformably overlies the various older formations of the Coastal Plain from the probably Miocene Grand Gulf to the early Cretaceous or late Jurassic Potomac. In some cases the Appomattox was laid down mantlewise upon strongly sculptured surfaces of older formations; when the land lifted at the close of the Appomattox period the waterways resumed their old lines, and the old sculpture was renewed; then the Columbia formation was similarly spread upon the Appomattox surface, and subsequently carved into like configuration; and this complex history has given rise to a complex distribution and interesting structural relations of the formation.

No characteristic or diagnostic fossils have thus far been found in the Appomattox formation; but its stratigraphic position, unconformably below the Pleistocene and unconformably above the Miocene (?), indicates an age corresponding at least roughly with the Pliocene. It represents a considerable part of a more or less vaguely defined series of deposits, variously called "Orange Sand," "Drift," "Quaternary," "Southern Drift," etc.; yet since this vaguely defined series included not only the Appomattox but also the basal gravel bed of the Pleistocene loess, parts at least of the Cretaceous or Jurassic Potomac formation, and other deposits of various ages, none of the old designations can be retained without material modification in defini-

tion; and it therefore seems wise to extend the term applied to the formation in the region in which it was first discriminated.

The sources of the materials of the formation have been fairly well ascertained: The pebbles were derived in part from the Potomac formation of the immediate vicinity, in part from the quartzite ridges and quartz veins of the Piedmont region and the Blue Ridge, in part from the silicious dolomites of the central Appalachian zone, and in part from the chert-bearing formations of the western Appalachian slope; and these pebbles were evidently distributed by the rivers flowing along the lines of the present great waterways of the region. A considerable element of the loam came from the same sources; but a part of it is always local and reflects the characteristics of the various sub-terranes.

In brief, the Appomattox formation forms a widespread terrane almost conterminous with the Coastal Plain between the Rappahannock and the Mississippi; and it is an easily recognizable structural and chronologic unit, entitled to first rank as a datum formation from which the stratigraphy and geologic history of the seaward portion of the Coastal Plain may be reckoned downward and backward. Although its wide extent and essential unity have been established by a large number of observations, the exposures have been correlated and the observations systemized by a method, which may be characterized as *homogenic*, largely inspired and well illustrated by this formation. This method is set forth in detail elsewhere.

On the close of the reading of this paper the Society adjourned to meet in the evening at 8 o'clock.

After the recess Mr. McGee gave a brief synopsis of the paper, which was followed by the discussion appended:

Professor C. H. Hitchcock: I would like to inquire if Mr. McGee can tell us the precise relations of this formation? Where does it come in contact with the Pliocene; and I do not quite understand its relations to the Pleistocene?

Mr. McGee: The formation is probably the exact stratigraphic equivalent of the Pliocene. In central South Carolina it is overlain by the Pleistocene Columbia formation and unconformably overlies the Miocene deposits, while fifty miles eastward, in the neighborhood of Charleston, fossiliferous Pliocene deposits are similarly intercalated between the Pleistocene Columbia formation and the fossiliferous Miocene formations.

Professor W. M. Davis: If I understood Mr. McGee correctly this afternoon, he said that the present streams follow inequalities which exist in the surface of the Columbia formation, but that the Columbia formation is really only a mask over similar inequalities in the previously eroded surface of the earlier formations. The question arises as to what terms should be applied to streams of that kind? Among the several terms that are now applied to rivers none fairly describe such examples as these. The streams are not strictly consequent on the Columbia, because the Columbia form is that of the underlying Appomattox formation; and they could hardly be said to be superimposed on the Appomattox, because their location accords too well with its surface. Has any name been in the mind of the author for such streams? It is a difficult matter to invent pertinent names that will be acceptable in general use; and yet in so clear a case as this of a new style of streams some new name must be introduced.

Mr. McGee: The class of rivers which I have described as cutting the Columbia and Appomattox formations alike is one which has definite existence, but for which no

name has hitherto been proposed. The class, too, is more comprehensive than Professor Davis' question might indicate. In the Buhrstone hill-land a well-defined drainage was established in late Eocene time; and rivers, streams, brooks, rivulets, down to the minutest rills even, and a corresponding topographic system, were developed. Subsequently the Grand Gulf formation of the Miocene was laid down and the old surface was buried in part, yet not so completely buried but that the post-Miocene drainage coincided with the pre-Miocene drainage. Then came the Appomattox formation, which was spread like a mantle over the surface; and upon it the primary drainage was once more renewed. Afterward the Pleistocene Columbia formation was laid down; and then for the fourth time was the drainage outlined on the original lines. This class of drainage has not hitherto received a designation; but from its mode of origin it might be called resurrected, or *palingenetic*.

Mr. C. D. Walcott: I have listened with a great deal of interest to Mr. McGee's paper, because it describes the determination of a geologic horizon over a great area without the aid of paleontologic data. It is true that the underlying unconformable series is determined by the contained fauna and gives the approximate horizon, but it is very rarely that we have an illustration of a satisfactory attempt to identify by the stratigraphy alone a formation so widely distributed as the Appomattox.

Professor James Hall: The communication shows very clearly that physical geology can be successfully carried on without the use of fossils.

The next paper was—

THE VALUE OF THE TERM "HUDSON RIVER GROUP" IN GEOLOGIC NOMENCLATURE.

BY C. D. WALCOTT.

It was discussed by James Hall, W. M. Davis, and Mr. Walcott. The paper and discussion are published in full among the memoirs, pages 335–356 of this volume.

The following papers were then read:

THE CALCIFEROUS FORMATION IN THE CHAMPLAIN VALLEY.

BY EZRA BRAINERD AND H. M. SEELY.

THE FORT CASSIN ROCKS AND THEIR FAUNA.

BY R. P. WHITFIELD.

Both of these communications are printed in full among the memoirs, orming the preceding pages 501–516.

The Society then adjourned until 10 a. m. of the next morning.

Session of Saturday, December 28.

The Society met at 10 o'clock a. m., President Hall in the chair.

Several announcements from the Council were made, after which the Secretary read a letter from Mr. Morris K. Jesup, President of the American Museum of Natural History, regretting the inconvenience to which the Society had been subjected owing to the unfinished condition of the building, and pledging a cordial welcome in case the Society should desire again to meet in the Museum.

Professor Cope moved a vote of thanks to the officers of the Museum, which was carried unanimously, and the Secretary was directed to send a suitable letter to Mr. Jesup as representing the Trustees of the Museum.

Professor W. M. Davis offered the following resolution:

Resolved, That a committee of three be appointed to confer with similar committees from the societies of Naturalists and of Physiologists in regard to the places and times of future meetings.

The resolution was adopted. The President appointed as such committee

W. M. Davis,
Alex. Winchell,
J. J. Stevenson.

The discussion of the papers read before adjournment last evening was next in order. C. D. Walcott, C. H. Hitchcock, E. Brainerd, and James Hall took part. The papers are published among the memoirs as above noted.

The next paper was read, in the author's absence, by Mr. C. D. Walcott. It is entitled—

THE STRATIGRAPHY OF THE "QUEBEC GROUP."

BY R. W. ELLS.

It is published in full, forming pages 453–468, plate 10, of this volume.

The next paper was—

THE CUBOIDES ZONE AND ITS FAUNA; A DISCUSSION OF METHODS OF CORRELATION.

BY H. S. WILLIAMS.

Remarks upon this paper were made by C. D. Walcott. It is published among the memoirs, pages 481–500, with plates 11–13.

The next paper read is represented by the following abstract:

GEOLOGICAL AND PETROGRAPHICAL OBSERVATIONS IN SOUTHERN AND WESTERN NORWAY.

BY GEORGE H. WILLIAMS.

[*Abstract.*]

The communication embodies the results of certain observations made by the author during the summer of 1888 in southern and western Norway, under the guidance of Professors Brögger and Reusch of Christiania, and in company with Professor Rosenbusch of Heidelberg and Dr. A. C. Lawson of the Geological Survey of Canada.

The points of special interest relate to the subject of metamorphism, which was studied on a series of excursions in two regions exhibiting, in sharp contrast, the effects (1) of the contact action of large eruptive masses upon nearly undisturbed Silurian strata; and (2) of intense dynamic action in metamorphosing both igneous and sedimentary material in a region of great orographic disturbance.

Since the early travels of Von Buch and Naumann, the region about Christiania has been classic as an example of the metamorphism produced at the contact of great eruptive masses; but the recent elaborate studies of Brögger show how much of value there was to reward a detailed examination of this same field.

Large areas of post-Silurian syenite, granite and porphyry have broken through the nearly horizontal Silurian beds, composed of thin, alternating layers of dark argillaceous, and light-colored calcareous material. The metamorphism is confined to the immediate vicinity of the contact, and is progressive—*i. e.*, proportional to the nearness of the eruptive rock. The most intense action is shown upon fragments included wholly within the syenite.

In the region about the Langesundfjord, southwest of Christiania, the conditions and are about the same, except that the metamorphosing agent is here nepheline-syenite, and particularly interesting on account of the great number of rare minerals which it contains. Two points worthy to arrest attention are (1) the extent to which the metamorphism of a sedimentary rock can be carried without destroying its fossils; and (2) the metamorphosing effects of eruptive masses upon other rocks themselves eruptive.

A specimen of limestone was exhibited from the immediate contact with the nepheline-syenite, near Brevig. It is completely changed by contact action, as is shown by the microscope, to an aggregate of garnet and diopside, and yet remains of crinoidal columns are still plainly visible in it.

The action of the syenitic rocks upon dikes of basic eruptives, present in the Silurian beds before the intrusion of the more acid masses, is of interest, inasmuch as the paramorphism of pyroxene to hornblende, which is now recognized as such a common result of regional metamorphism, is here seen to have been accomplished by contact metamorphism alone.

A description was also given, illustrated by a diagram and specimens, of the Horterkollen granite mass, which has raised the overlying Silurian strata in the form of a laccolite, though its base is not visible, and hence it is not definitely known whether or not the sedimentary beds lie below as well as above the intrusive mass. This mountain lies about twenty miles due west of Christiania, and is fortunately exposed on its south side in a natural section from base to summit. The structure of the

granite is coarse below but rapidly becomes finer grained toward the contact, and is almost cryptocrystalline along the edge of the sedimentary beds. The thick covering of Silurian strata is continuous over the entire mass, their dip following the contact, even down the steep eastern slope. The metamorphism of these overlying beds is plainly due to the granite, and anastomosing dikes of the latter rock penetrate them vertically, but without reaching the present surface.

On leaving the Christiania region for the western coast of Norway, the opportunity was enjoyed of examining the regionally metamorphosed eruptive and sedimentary rocks near Bergen, under the guidance of Professor Hans Reusch, whose well-known works* on the geology of this district have given it a world-wide fame. The remarkable mica-schists of Vagtdalen were visited, containing, in spite of their highly crystalline character, well-preserved remains of trilobites and corals. Moreover, where the metamorphism has completely destroyed the fossils in the schists, they are often preserved in intercalated calcareous lenses. (Specimens of all these rocks were exhibited to the Society.)

Much more of importance in its bearing upon regional or dynamic metamorphism was seen near Bergen and on the island of Bemmelö, further to the south. Time, however, forbids the further entering into detail; but the series of specimens will serve, better than words, to illustrate to those who are interested in the subject, what are the most striking facts.

Suffice it, in conclusion, to indicate certain points which seem capable of general application to metamorphic rocks, and to the truth of which these observations in Norway offer strong corroborative testimony:

1. The *mineralogical* changes produced in a given rock by both contact and dynamic metamorphism are in general similar, while the *structural* alterations brought about by the same agencies are usually in striking contrast. In the case of the basic eruptives above mentioned the paramorphism of pyroxene to hornblende is accomplished either within the contact zone of syenite or by orographic pressure; although it is only by the latter means that the rock is converted into a schist by the development of foliation.

2. If the action of dynamic metamorphism is carried far enough it is capable of producing the same result from rocks originally most distinct in character and origin. An eruptive mass and a sediment, if sufficiently alike in chemical composition, may, when subjected to intense pressure, develop into foliated rocks which cannot be distinguished. It is, therefore, possible to trace out the origin of the crystalline schists only up to a certain point. We may separate those which are igneous from those which are clastic, so long as any distinctive characters remain; but if, as is very often the case, the original structure has been obliterated by metamorphism, such a separation becomes hopeless.

Professor J. S. NEWBERRY: I would ask Professor Williams to add a single fact to the very clear and interesting exposition he has given to us. How far has there been, in these different cases, substitution or transfer of material? I would ask if he has the chemical constitution of the unaltered and the altered rocks to compare.

Professor WILLIAMS: This differs very much in different cases. Here we have a limestone transformed into an aggregate of garnet and pyroxene; this means a very considerable substitution. Some limestones are, however, silicious; and a highly sili-

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* These are: *Silurfossiler og pressede Konglomerater i Bergenskifrene*, 1883, translated into German by Baldauf; and *Bömmelöen og Karmöen med Omgivelser*, with an English summary of contents, 1888

cious and highly magnesian limestone would not require a great addition of material to change it into an aggregate of garnet and diopside. As regards the basic rocks, I cannot speak with as much certainty of the Norwegian occurrences as of other rocks of a similar character in the neighborhood of Baltimore, where like changes have been produced by regional metamorphism. Here the resulting products, composed of feldspar and hornblende, do not in any particular differ in chemical composition from the original rock, composed of pyroxene and feldspar.

Professor B. K. EMERSON: I desire to add a word, partly from interest in the speaker and in recognition of the admirable way in which the matter has been presented by him, and partly from reminiscences that came up of travel many years ago in the region he has described. This discussion of regional metamorphism brought to my mind the work of President Hitchcock upon the same subject, and especially his work on the fossiliferous Devonian schists at Bernardston, Massachusetts. On examining a large series of these Bergen specimens with Professor Rosenbusch a few years ago, I found that the Bernardston Devonian locality described so long ago by President Hitchcock and Professor Dana affords representatives of all, or the major portion of those rocks—quartzite with all the pebbles rolled out and cut sharp by faulting and jointing, hornblende schists in every variety except those which seem to have come from the metamorphism of eruptive rocks (that is, hornblende schists that seem to come from the metamorphism of limestone but show no trace of tufa or volcanic origin), beds of the most compact and pure magnetite with fossils immediately above and below them, and these fossils in highly crystalline limestone cut through by granite veins and in mica-schists piece for piece like those taken from Bergen. These things, like the facts of history, have to be re-described and re-written, and come at last to be believed. Of course the work of President Hitchcock was done without the aid of the microscope, and it was pushed far beyond the limits of the field at Bernardston.

I was surprised in passing recently one of the college buildings at Amherst which is built of gneiss to see that several of the blocks showed the altered pebbles of the conglomerate of which the rock was made. This is the so-called Munson granite that stretches across the state east of Amherst; and that same conglomerate granite wraps around the Archean of the western part of the state and forms there a coarse shore deposit. This granitoid gneiss was supposed by President Hitchcock to be the last term of the metamorphism of a conglomerate. It seems to me that the distinction between the regional metamorphism and the metamorphism caused by manifest contact of eruptive rock, where the two effects are superimposed, will be found in the introduction in the latter case of chemical materials that have been brought up with the eruptive rocks. Any contacts which show, as those I have studied in Massachusetts, the presence of minerals containing boracic acid and a large increment of alkalies, as compared with the same bed more removed from the intrusive rock, enable one at times to distinguish quite clearly between the regional and the contact effects. This is especially clear with aluminous sediments when the normal metamorphism develops chiastolite, ottrelite, staurolite, garnet, graphite. The contact influence of the eruptive adds coarse muscovite in abundance, feldspars, tourmaline, cordierite, and suppresses (resorbs) for the most part the purely aluminous silicates of the first group, though their former presence may be noted by their pseudomorphs in muscovite.

The next paper is represented by the following abstract:

CRETACEOUS PLANTS FROM MARTHA'S VINEYARD.

BY DAVID WHITE.*

[*Abstract.*]

An historical review of the opinions of geologists, during the first half of this century, concerning the age of the strata extensively exposed at Gay Head, at the western end of the island of Martha's Vineyard, shows a general agreement in correlating those strata with the Alum bay clays in the Isle of Wight, chiefly on account of their stratigraphical resemblance. Specimens of a Cretaceous fauna have been found, but the rolled appearance of these and the presence of more recent fossils in the same series have led to the conclusion that the Gay Head terrane is of lower or middle Tertiary age. Within the last year, however, this series has been the subject of an elaborate stratigraphical description by Professor N. S. Shaler, who, in his report on the geology of Martha's Vineyard, names it the "Vineyard series," and concludes, without adducing the paleontologic evidence, that it is late Miocene or Pliocene.

A careful search made last summer, in company with Professor Lester F. Ward, of the U. S. Geological Survey, resulted in the discovery and collection of plants in the carbonaceous clays in the Vineyard series at several points about Gay Head, at Peaked hill, and at Nashaquitsa, and from concretions found in the first and last named localities. Fossil wood was found wherever the series was met with. The collection, which bears an archaic aspect, embraces cryptogams, gymnosperms, and angiosperms. Most of the species seem unlike any before described.

Of the species as yet identified, *Sphenopteris grevillioides*, Hr., has been found also in the Kome (lower Cretaceous) beds of Greenland; *Sequoia ambigua*, Hr., occurs in the Kome beds and the lower Atane (middle Cretaceous) of Greenland; *Andromeda parlatorii*, Hr., formerly described from the Dakota group of Kansas and Nebraska, has also been identified in the lower Atane of Greenland, and from strata probably of Cretaceous age in the Bozeman coal mines of Montana; *Myrsine borealis*, Hr., occurs in the "*Liriodendron* bed" (lower Atane) in Greenland; *Liriodendron simplex*, Newb'y (*L. Meekii*, Hr., in part), one of the few species as yet published from the Amboy clays, is one of the most abundant species in the flora at Gay Head, where it is found associated with forms identical with some found by Heer in the famous "*Liriodendron* bed" of the lower Atane, and in the Patoot (upper Cretaceous) of Greenland; a *Sapindus*, probably referable to *S. Morrisoni*, Lx., has been found in the Dakota group of Nebraska and the Patoot beds of Greenland; *Eucalyptus geinitzi*, Hr., next in abundance, has been found in the "*Liriodendron* bed" of Greenland, is abundant in and characteristic of the middle Cretaceous of Bohemia, and also appears at the same stage (Cenomanian) in Moravia. The remains of the *Eucalyptus* nuts are marked by furrows filled with a fossil resin "indistinguishable by ordinary tests from amber." The fossil contents of these oil or gum vessels suggest that a part at least of the so-called amber found about Gay Head and in the Cretaceous of New Jersey, where also eucalypts occur, may be the fossilized exudation of the contemporaneous "gum-trees."

All the previously described species thus far identified at Gay Head have been found exclusively in the Cretaceous, and all but *Sphenopteris grevillioides* were present in the middle Cretaceous. Although our flora seems to be more directly related to that

*Printed in full in the Am. Jour. Sci. for February, 1890.

of the middle Cretaceous of Greenland than to that of the Dakota group, there is every reason for believing that it will prove to be largely identical with the rich but as yet unpublished flora of the Amboy clays. The Gay Head flora indicates an age certainly Cretaceous, and probably middle Cretaceous, for the terrane in which it was deposited.

The occurrence of Tertiary elements in the fauna of the Vineyard series raises the question as to whether the plant-bearing concretions are not exotic. The structure, composition, number, size, position, and relations of these concretions to the containing matrix join in indicating their present existence in the place of their original formation. Numerous stems and fragments, together with the eucalypt fruits, are found in the matrix of the limonitic conglomerate. The extra-concretionary plants found in the carbonaceous clays at various horizons, though mostly indeterminable, seem to agree with the species found in the concretions. At Nashaquitsa the concretions were observed by Professor Ward and myself apparently in the process of formation, the leaves sometimes lying partly within the concretion and extending outward into the homogeneous matrix.

Similar plant-bearing concretions are found in the Amboy clays on Staten island and in New Jersey. The extension of these middle Cretaceous clays as far eastward as Glen Cove on Long island is now generally accepted. If the Vineyard series is not itself a farther extension, it must, at least, have been derived in part, and with the minimum distance of transportation, from such a continuation of the middle Cretaceous to the eastward, along the south of New England.

The present paper is the result of a preliminary study. Before the age and origin of this series can be unquestionably determined, there is need of further work in all branches of its paleontology, taken side by side with the study of its stratigraphy.

Dr. J. S. NEWBERRY: This is the first opportunity I have had to see any of the plants spoken of by Professor Shaler, but there can be no doubt that they represent the flora of the Amboy clays. I have been collecting fossil plants from New Jersey for the last twenty years, have already some thousands of specimens, and have fifty plates of this Amboy flora drawn and arranged for publication. I have traced the Amboy clays from New Jersey across Staten island and along the north shore of Long island to Sea Cliff and Glen Cove, and have long been of the opinion that the formation extends the entire length of the island. Now, Mr. White has shown that it underlies Martha's Vineyard as well, for the leaves and fruits displayed on the screen are all found in the Amboy clays. I will not now say anything further about the characteristics of the Amboy flora, only that it has some things in common with the flora of the Dakota group, but contains many more plants found in the Atane beds of Greenland and the Cretaceous clays of Aachen [Aix-la-Chapelle]. Its geological position is middle Cretaceous, or at the base of the White Chalk.

Professor LESTER F. WARD: My principal object in coming to this meeting was to listen to this paper, as I was associated with Mr. White in his work and am deeply interested in it.

I desire merely to emphasize the great importance of the results at which he has arrived. Not until the past season has anything definite been known of the fossil flora of Martha's Vineyard, the few fragments figured by Hitchcock not having been determinable and having no geognostic value. As Mr. White has remarked, the ablest geologists in the country have long been at work upon the question of the age of the Gay Head beds, and, as shown by the older as well as by recent papers, especially those of Professor Shaler, great differences of opinion and doubt as to their age have prevailed.

The discovery by Mr. White of undoubted Cretaceous fossil plants has settled that question so far as the particular strata from which these plants were found are concerned. In all his recent papers, including the one read before the Society on Thursday last (pp. 443–452), Professor Shaler has insisted that all except the very base of the Gay Head section is Tertiary and even Miocene or Pliocene.

I do not pretend that the entire section at Gay Head and Nashaquitsa cliff is necessarily Cretaceous. The plants were found in the Gay Head section near the middle, and it is very possible that, considering the extent of the beds and the length of the section, the overlying strata may be Tertiary, even Miocene. But if there is a great thickness lying above these beds, so there is a great thickness lying beneath them, and therefore the section must extend far down into the Cretaceous. It would seem then that Mr. White's investigations during one short season have done more to settle the age of these beds than all that has been done before.

I gladly testify to the indefatigable zeal with which Mr. White pursued his investigations against the greatest difficulties and discouragements. It required much careful thought and labor to ascertain in what particular manner the plants were preserved; but after this had been fully settled he was very successful in finding them, although they were not abundant; and he persisted until his collection amounted to five barrels of very excellent material, which is being elaborated at the National Museum.

Mr. F. J. H. MERRILL: It is seldom that an opportunity is afforded for determining the true stratigraphy of the Gay Head section. The speaker visited it in 1884 and concluded as a result of his examination that the beds were extensively repeated by faulting; but on visiting the locality in 1887, with Professor N. S. Shaler, he found the aspect of the section so much altered by landslides that he was unable to show the evidence upon which he had based his conclusion. Subsequent exposures have again revealed the truth as reported by Professor Shaler at this meeting (*ante*, pp. 443–452). During his first visit the writer found a number of clay-ironstone nodules enclosing fragmentary leaf-prints, which were considered by Dr. Newberry to be of Cretaceous age, but the impressions were poorly preserved and their nidus in the section was uncertain, so that no decisive value could be attached to them. Although the Cretaceous leaf-prints reported by Mr. White were undoubtedly in place, they do not prove the Cretaceous age of the whole Gay head section. They are from the lower half of the series. The greensand beds, which are in the upper half, contain Miocene Tertiary fossils, shark teeth of the genera *Charcarodon* and *Oxyrhina*, bivalve casts, probably of *Tellina biplicata*, Say, and fragments of crustaceans. This greensand deposit is apparently secondary, having been derived from some pre-existing bed and re-deposited under conditions of disturbance and violence abnormal to greensand beds. The crustacean fragments in particular have been much rolled and wave-worn. On this evidence we may conclude that the greensand beds were laid down not earlier than the close of the Miocene.

The opinion of the writer that the Gay Head strata were post-Pliocene was chiefly based on the evidence of a stratum of post-Pliocene sand, which is the uppermost member throughout the section, being repeated frequently by faults and at one point containing fragments of *Venus mercenaria* and other Quaternary shells. As this bed is apparently conformable to those beneath it, the writer concluded that a considerable portion of the Gay head series, if not the whole of it, was laid down in post-Pliocene time. It may be, however, that future investigation will demonstrate the presence of Cretaceous, Tertiary, and Quaternary strata at Gay head.

At the close of this discussion the Society took a short recess.

After recess, the first paper read was—

SANDSTONE DIKES.

BY J. S. DILLER.

The paper was discussed by W. M. Davis and B. K. Emerson, and is published among the memoirs, forming pages 411–442, with plates 6–8, of this volume.

This paper was followed by—

ILLUSTRATIONS OF GLACIERS IN SELKIRK MOUNTAINS AND ALASKA.

BY A. S. BICKMORE.

A series of elaborate lantern slides were thrown upon the screen and briefly described.

The next paper was—

SOME RESULTS OF ARCHEAN STUDIES.

BY ALEXANDER WINCHELL.

It gave rise to discussion by C. R. Van Hise and Professor Winchell. The paper is published among the memoirs, *ante*, pages 357–394.

The paper represented by the following abstract was then read:

SIGNIFICANCE OF OVAL GRANITOID AREAS IN THE LOWER LAURENTIAN.

BY C. H. HITCHCOCK.

[*Abstract.*]

In the primitive crystalline regions, observers have noted that the supposed oldest portions of the Laurentian consist of oval, ovoidal, elliptic, or variously elongated areas, usually foliated. Such are the formations called K_1, K_2, K_3 by Percival in the "Western Primary" of his Connecticut map, as well as his B of the "Eastern Primary." The first-named are part of a series that extend through western Massachusetts into Vermont, and would be represented in the "Laurentian protaxis of the Green mountains" as described by Professor J. D. Dana in the Bulletin G. S. A., this volume, page 36. In New Hampshire they may be represented by the porphyritic gneiss and the Bethlehem gneiss. Dr. A. C. Lawson describes similar areas in

the Rainy lake district north of Lake Superior (Part F, Ann. Rept. Geol. Canada, 1887), and Dr. A. Winchell has referred to similar cases in the paper just read.

The characteristic features are usually the following: 1. The area was originally highest in the center, though now it has reached the senile topographic stage. 2. There is a concentric arrangement of the rocks and minerals. Thus, in a small area in Hanover, New Hampshire, the interior core displays porphyritic crystals of orthoclase, while the main mass consists of a rather coarse protogenic gneiss. The outer band, not more than 100 or 200 feet thick, has a superabundance of chlorite with biotite, but must not be confounded with what have been called Huronian schists in the neighborhood. This area is perhaps ten miles long and four miles wide. 3. The foliated planes possess the anticlinal quaquaversal arrangement. Subsequent action has folded these planes just as if they indicated an original sedimentation.

The significance of these facts depends upon the interpretation given to the foliation. If these represent lines of sedimentary accumulation, then the areas constitute the very oldest known stratified deposits. As they are anticlinal in form they furnish no evidence of a basin structure; or if the older foundation exists it has never been observed. There seems to be no evidence of sedimentation in these basal layers—all the supposed conglomerates of the Archean being situated in the upper part of the group. The facts are at variance with a popular notion of an indefinite series of systems, each one formed from another concealed from view. The areas described are the oldest known, or fundamental rocks.

If the other, or igneous view of origin be accepted, essentially the same view of age must be entertained, for the spaces between these primitive areas are composed of later Archean or Paleozoic rocks, and there are no apophyses or veins extending into the newer series. Where these are observed, as is claimed by Dr. Lawson, there is reason to believe in their later igneous development. In the cases examined, every part of the concentric structure is apparently of the same age, the zonal condition resulting from freedom of motion in a plastic mass so that there may be a segregation of like mineral constituents into separate bands.

The origin of the igneous masses may be compared to the building up of oceanic islands of the present day from volcanic ejection. I have elsewhere suggested * that in New Hampshire the rounded areas of the oldest rocks are numerous enough to have constituted an archipelago which may have been the beginning of the Archean continent in New England.

The areas of granite, syenite, and porphyry in the White mountains correspond topographically with the supposed original Laurentian areas, but they lack the planes of foliation. Hence they cannot have been subjected to the influences which have been brought to bear upon the former. Granting a correspondence between the two, the one may represent youth and the other old age of igneous overflows.

Professor G. H. WILLIAMS: It is interesting to see how the same facts may suggest to different minds, different interpretations. After what I have seen in Norway and elsewhere an explanation occurs to me exactly opposite to the one which Professor Hitchcock has suggested. The center of the mass is, I think, the youngest, while the other layers are to be accounted for as having been approximately horizontal strata, pushed up by a molten mass rising from below after the other material was formed. This eruptive rock has altered the strata progressively from the center.

* Address as Vice-President Section E, Proc. A. A. A. S., vol. XXXII, 1883.

The next paper was—

PORPHYRITIC AND GNEISSOID GRANITES IN MASSACHUSETTS.

BY PROFESSOR B. K. EMERSON.

[*Abstract.*]

Referring to an unpublished geological map of the central part of Massachusetts, and confining attention to the region between the Berkshire limestones and the Boston basin, it was remarked that the country consists of a great series of mica, quartz, and hornblende schists, all presumably Paleozoic, and eight principal bands of highly feldspathic rocks (more or less interrupted), broad where they enter the state on the north and narrowing southward, and for the most part terminating before reaching the south line of the state. They are granites and granitoid gneisses, in small part Archean, in larger part Cambrian, and in largest part intrusive.

The western band is a complex of Archean and Cambrian—a row of small Archean ovals, exposed by erosion of the Cambrian conglomerates and conglomerate gneisses, extending quite across the state. The Hinsdale area is typical of the Archean ovals. A center of coarse allanite and magnetite gneiss surrounded by a band of coarse limestone, like that of Ticonderoga, carrying phlogopite, chondrodite, etc. Outside the limestone is a graphite gneiss carrying a characteristic blue quartz.

This Archean series is bounded by a broad area of a coarse Cambrian conglomerate, mostly changed into a white biotite gneiss, like the quarry stone of Monson and Pelham. It is itself quarried extensively in Becket.

The Allanite gneiss dips beneath the limestone and so outward—the quaquaversal arrangement is perfect, though no special weight is put upon this fact in determining the age of the beds. This is deduced rather from the clearly Laurentian type of the Archean gneisses and limestones, and from the facts (1) that the same conglomerates, in their northward extension in Clarksburg, have been found by Mr. C. D. Walcott to contain Cambrian fossils, and (2) that they rest in strong unconformity upon the Archean series beneath.

This can be seen clearly in a fine exposure along the brook south of the Dalton Mountain Club house, on the old Hinsdale-Dalton road. Archean areas of this type extend across Massachusetts and Connecticut, but to the north are two ovals of different type—the Hoosac tunnel and Clarksburg areas. Here the same Cambrian conglomerates and white biotite gneisses surround areas of a coarse porphyritic granite; and Mr. J. E. Wolff, who has developed this difficult territory with the greatest perseverance and success, considers these granites certainly pre-Cambrian, and has proved conclusively that the conglomerates are unconformable upon them.

The broad band that crosses the state east of the Connecticut, containing the Northfield and Pelham quarries, agrees with the Cambrian conglomerate in character and, I think, in age. It is a broad, very flat anticlinal, throwing off the whole schistose series on either flank. It shows traces of pebbles here and there, and contains a great bed of slightly actinolitic quartzite.

The other bands come under a different category. They lie along large synclinals instead of anticlinals. They are commonly biotite granite—fine grained to coarse porphyritic—rarely varying to muscovitic and hornblendic varieties. The texture

varies from massive to distinctly foliated, and the contacts on adjoining rocks are those of intrusive masses.

I would call these great bodies of granite *batholites*, employing the word suggested by Edouard Suess, after the analogy of the word "laccolite," coined by Mr. G. K. Gilbert. They have melted their way up through a great thickness of the folded strata, often absorbing much of the latter into their own mass. This is well shown in the central batholite in the series west of the Connecticut, which extends across Hatfield and Williamsburg. In its eastern third it cuts through a great thickness of hornblende schists, and is a heavy hornblende granite. In its middle third it comes in contact with less hornblende schist and with much limestone, and it is here a hornblende-biotite granite. The remaining western portion is bounded and was formerly covered by muscovite-biotite schists, and the granite is here white, with little biotite and often much muscovite. The great mass is cut everywhere by a very great number of dikes of a coarse muscovite granite, which seem to represent later intrusions of the central portion of the mass into shrinkage cracks in the already cooled peripheral portions, and thus to represent more truly its original composition.

The batholites lie in several series of ovals parallel with the strike (or these are fused into single broad bands) along the centers of great synclinals, the weakening along the base of the latter having furnished a favorable outlet for the fused material. The surface of contact between the granite in these batholites and the superincumbent schists must have been very irregular, and a broad area of contact metamorphosis must have extended out from this surface; and the various sections presented by different erosion surfaces enable us to reconstruct the batholite with some fullness.

Thus, in the center of the Worcester argillite is a broad oval where the argillite is changed to a pure mica schist filled with the chiastolites found in all cabinets. There is no trace of granite for miles around, but I have no doubt that the change in the argillite is due to a buried batholite, like those a few miles south in the city of Worcester.

Again, where the schists are vertical, sheets may have extended deeply into the plastic mass and have retained their dip and strike because they retained their connection with the superjacent schists. Thus in the Hatfield batholite, starting from the hornblende schist, one finds in the line of its strike for several miles across the granite fragments of the schist with true dip and strike, and, in the line of the limestone and the mica schist, similar fragments of these rocks. When the rocks are more nearly horizontal, great floes of the schists float upon the granite, as the fibrolite schists on the Belchertown granite, and the Carboniferous conglomerate upon the Harvard granite.

The zonal character of the contact metamorphosis around these batholites is interesting, especially in aluminous sediments. The first wave of heat develops the easily formed minerals, fibrolite and chiastolite; stronger heat, staurolite and garnet; then the first influx of alkaline waters from the granite forms pseudomorphs of these in muscovite, and with increasing heat feldspars develop. So the highly altered rocks nearest the intrusive mass have often passed through all the stages one passes over in going from the outer zone inward. Thus, in the Carboniferous argillite in Harvard one finds masses of interlaced prisms of andalusite, of the largest size and finest pink color, enclosing crystals of fibrolite in abundance (the two not orientated to each other), and the whole in every stage of change to coarse muscovite. This preserves three stages which were plainly passed over in succession, and nearer the granite

large feldspars are interspersed. In the Hatfield argillite, a zone of delicate chiastolites is succeeded inwardly by a zone where the chiastolites are changed to a mixture of muscovite and minute twins of staurolite (the mass still retaining the shape and black cross of the chiastolite) by the influence of greater heat and alkaline solutions; and nearer the granite the whole changes to sericite schist, chlorite schist, and finally hornblende and feldspar appear near the contact with the hornblende granite.

The outcrops which have been discussed have for the most part been called granites heretofore. This, however, is true of them, that they are often entirely indistinguishable from the Cambrian conglomerate gneiss where both are developed as medium-grained biotite granites.

The more perplexing cases remain for consideration. These are the broad bands of biotite granite, often well foliated, which stretch across the state with a width of five to twenty-five miles. They may be called the Princeton, Barre, Athol, and Orange bands. The Princeton band starts at the north west corner of Worcester and, gaining soon a width of ten or twelve miles, runs north through Fitchburg, where are great quarries, and on into New Hampshire, where it is called "Concord granite" by Professor C. H. Hitchcock on the map of the second New Hampshire survey, and classed as "Montalban."

On being mapped, it cuts across the Carboniferous and older schists as an intrusive mass. Though often foliated, it is more often massive, and its foliation cannot be harmonized with that of the adjacent schists. It has a clear zone of contact metamorphosis—fibrolite schists changes to garnet and staurolite schist, argillite to chiastolite schist, quartzite becomes gneissoid, and tourmaline is developed for miles along the border.

Lying in the middle of this granitic area, Mount Wachusett is in structure distinctly laccolitic, and owes its existance to a great mass of fibrolite schists—a portion of the former cover of the batholite. If a book be laid on its side with its ends directed north and south and a slight pressure be exerted on the leaves till they bend up slightly and separate, forming three or four lens-shaped cavities, then will the leaves represent the fibrolite schists, and the cavities the intruded granite; and if now the eastern half or three-fourths be removed, the remainder will be a good model of the mountain.

I am compelled thus to consider the whole great mass, more than fifty miles long and above five miles wide, as an elongated batholite occupying a large synclinal in the schists. The Athol band is still more clearly an intrusive block. The other two combine so equably the peculiarities of the Cambrian conglomerate gneisses and the batholitic granites just described that I hesitate as to their interpretation.

By reason of the pressure for time, the next paper on the programme was read by title only. It was—

THE PRE-CAMBRIAN ROCKS OF THE BLACK HILLS.

BY C. R. VAN HISE.

The paper is printed in full among the memoirs, forming pages 203–244, with plates 4 and 5, of this volume.

The paper next in order was read by the author:

THE INTERNAL RELATIONS AND TAXONOMY OF THE ARCHEAN OF CENTRAL CANADA.

BY A. C. LAWSON.

Owing to the shortness of time left, there was no discussion on this communication. It forms pages 175–194 of this volume.

The next paper was read by title, and the author presents the following abstract:

ON THE INTRUSIVE ORIGIN OF THE WATCHUNG TRAPS OF NEW JERSEY.

BY FRANK L. NASON.

[*Abstract.*]

The study of the Triassic sandstones of New Jersey by the state survey during the summer of 1888 resulted in the discovery or re-discovery of a trap conglomerate on the northwest border of the formation. This trap conglomerate was found near Montville and also at Jacksonville, three miles northeast, in heavy beds. This was at once assumed to be conclusive proof that the Watchung traps were of extrusive origin, and that the pebbles of trap came from these hills.

Much as the late Dr. Cook was opposed to the extrusive theory, he considered this discovery to be the strongest positive argument yet advanced by the upholders of the extrusive origin in support of their views. His hope was that another source would be found for the trap pebbles, and the question thus be left yet open, at the very least. Field work during 1889 has disclosed the following facts:

1. These trap bowlders have come from the northwest. The reasons for believing this are that the pebbles are mingled freely with pebbles of gneiss and quartzite and limestone. These formations are on the northwest.

2. The traps exposed on Towakhow, Second and First mountains, are amygdaloidal and fine grained. The trap pebbles in the conglomerate are coarse grained, with no trace of amygdules.

3. The trap pebbles of the conglomerate have a great abundance of quartz, while those of the Watchung mountains are almost free from quartz. Numerous trap dikes in the Archean in the northwest, and near by, correspond with the trap pebbles in being coarse grained and in having quartz.

4. So far as is known, the conglomerates in the vicinity, Cushetunk, New Germantown mountains, and at Pampton Lake, are free of trap pebbles. These traps are all regarded as extrusive by the holders of this extrusive theory. It is held that the facts above stated thus nullify any conclusions which otherwise would follow from the presence of a trap conglomerate.

5. The conglomerates which are made up wholly or in part of limestone, trap and gneiss, on the northwest border of the Trias, are but slightly conformable to the general Trias. This is contrary to a statement in the annual report of the state geologist for 1888. These conglomerates have more the appearance of having been torrential

deposits poured into a lake by streams from the Archean. They could very well have been formed by wash from the Archean almost independent of streams.

6. The appearance of angular limestone pebbles mingled with well rounded quartzite and gneiss pebbles shows that the conglomerate was rapidly formed, else the limestone pebbles would have been entirely worn away. This conglomerate might well have been formed during the disturbance caused by the faulting of the rocks and the outpour of the Triassic traps.

The next paper was—

ON THE PLEISTOCENE FLORA OF CANADA.

BY SIR WM. DAWSON AND D. P. PENHALLOW.

It was read in abstract by Mr. F. D. Adams. The paper is published among the memoirs, forming pages 311–334.

This was followed by—

THE FIORDS AND GREAT LAKE BASINS OF NORTH AMERICA CONSIDERED AS EVIDENCE OF PREGLACIAL CONTINENTAL ELEVATION AND OF DEPRESSION DURING THE GLACIAL PERIOD.

BY WARREN UPHAM.

From Norway, Denmark, and Iceland we receive the word fiord, meaning a deep, narrow inlet of the sea, extending in a river-like course many miles into the land. The continuation of the same valley is occupied by a stream, and there are often tributary fiords and streams entering the main fiord on either side. All the topographic and geologic characters of fiords prove, as first shown by Dana, that they are partly submerged channels or valleys which were eroded by rivers when a greater elevation of the land raised the bottoms of the fiords above the sea level.

The northern Atlantic and arctic shores of North America and Greenland, not less than the opposite shores of northwestern Europe and Iceland, are indented by very remarkable and abundant fiords, from Maine and the Gulf of St. Lawrence to Labrador, Hudson strait, the east and north parts of Hudson's bay, and to the most northern latitudes explored on both coasts of Greenland and in the archipelago between Baffin bay and the mouth of the Mackenzie. Again, on the western side of our continent the same evidence of formerly greater elevation of the land and present submergence is found on the coast of Washington, British Columbia, and Alaska to the Yukon, in almost countless fiords, and in the channels, straits, and sounds, separated from the open ocean by high islands, which shelter nearly the entire passage by steamboat from Victoria to Sitka.

The fiord best known and most visited by tourists in eastern North America is the impressively sublime gorge of the Saguenay. The depth of this fiord is stated by Sir William Dawson to be from 50 to 140 fathoms—that is, 840 feet—below the sea level, along an extent of about fifty miles from the St. Lawrence to Ha-Ha bay, while in some places the bordering cliffs rise abruptly 1,500 feet above the water, making the whole depth nearly 2,400 feet, with a width that varies from about a mile to one and

a half miles. It is thus known that the region of the Saguenay formerly stood at least about a thousand feet higher than now.

Scarcely less grand is the gorge through which the Hudson pierces the mountainous Archean belt between Newburgh and Haverstraw; and if there should be a depression of the land, faster in its rate than the filling of the valley with sediment, the tidal portion of this river, from Albany to New York, would become a fiord. But the former channel and fiord of the Hudson, which were a continuation of the present valley but are now submerged beneath the sea outside the Narrows, are of greater interest in our present inquiries, as they supply most important testimony concerning the geologic time and conditions of the erosion of the North American fiords and the preceding uplift and succeeding subsidence of the northern part of this continent.

Soundings of the sea approaches to New York, made in 1842 and 1844 by the United States Coast Survey, were long ago shown by Professor Dana to afford evidence of a submarine continuation of the Hudson river valley; and during the years 1880 to 1884 minute hydrographic surveys of this part of the submerged Atlantic slope of the continent supplemented what was before known, obtaining very significant observations. A report of this work, written by A. Lindenkohl of the United States Coast and Geodetic Survey, and read at the meeting of the National Academy of Sciences April 22, 1885, by J. E. Hilgard, was published in the American Journal of Science for June of that year. The submarine valley or channel begins to be noticeable ten miles east by south off Sandy Hook, at a depth of 19 fathoms, and extends first southerly about ten miles; thence, after bending eastward in the next five miles, it maintains a straight course, S. 60° E., to its bar, which is eighty miles from Sandy Hook. The soundings to the top of the channel's banks and the submarine plain on each side along the first ten miles, to the bend, are 18 to 20 fathoms; and the depth of the channel, from the top to the bottom of its banks, increases from one or two fathoms to 15 fathoms, or 90 feet. Onward for the next twenty miles the depth of the channel continues at 15 fathoms; but the soundings to the top of its banks and the adjacent plain increase to 27 fathoms. Along the next ten miles the channel decreases in depth to 11 fathoms, in ten miles more to only 7 fathoms, and then in ten miles to 5 fathoms. At five miles farther, or seventy-five miles from Sandy Hook, its depth is two fathoms, and it ceases within the next five miles. Through the forty miles in which the depth of the channel decreases, the soundings to the top of its banks increase from 27 to 43 fathoms, or 258 feet.

The average slope of the banks is one degree, and the width of the included channel from three-quarters of a mile to one mile; but in the bend the slope is increased to three degrees and the width contracted to an eighth of a mile. Specimens of the sea bottom brought up by the lead from the bed and banks of the channel are sandy clay, evidently the continuation, as believed by Mr. Lindenkohl, of the Tertiary "sandy clay strata" found occupying the southeastern part of New Jersey by the geological survey of that state. The adjacent plain differs from the channel in being overspread with sand and gravel, which appear to be of Quaternary age and the continuation of the expanse of modified drift that forms the south side of Long island, sloping down from the front of the terminal moraine.

Beyond the bar of fine sand which terminates this channel, a submarine fiord is found in the line of its continuation, extending about twenty-five miles, with a width of three miles, to the edge of the steep continental slope at a distance of about one hundred and five miles from Sandy Hook. The adjacent flat sea bottom descends

along these twenty-five miles from 50 to 100 fathoms. The bed of the fiord, as described by Lindenkohl, commences with a depth of only about 10 fathoms below the general plain, or 60 fathoms below the sea level; but the soundings in the fiord increase to 200 fathoms within the first mile, and its deepest sounding, 474 fathoms, is close to its outlet. "This outlet to the ocean," writes Lindenkohl, "is in the shape of a bar with a depth of about two hundred fathoms. For half its length, from its middle to the bar, this ravine maintains a vertical depth of more than two thousand feet, measuring from the top of its banks; these banks have a nearly uniform slope of about 14°. It remains to be stated that the bottom and the sides of the ravine are composed of a green sandy mud, and that the adjacent flats, unlike those of the submerged channel, show the same material."

This fiord under the sea demonstrates that the border of the continent in the vicinity of New York has been uplifted 2,800 feet higher than now, while a large stream here flowed down from the equally or perhaps more uplifted basin of the Hudson, proving that the elevation affected a very extensive area. The date of this uplift is shown to have been after the deposition of the Tertiary beds of New Jersey, in which the channel and fiord are eroded; and the length of time during which the land stood at this height was manifestly short, geologically speaking, else the fiord would be much longer, occupying the place of the comparatively shallow channel.

When subsidence of the country ensued, a very massive bar was formed by coastwise wash across the mouth of the Hudson fiord, attaining a height of 1,600 feet above its bottom, and the crest of this bar is now about 1,200 feet below the sea level. A later stage in the subsidence, when the land was only about 260 feet above its present height, is marked by the sand bar at the end of the submarine channel. From then to the time of formation of the present bar the depression of the land seems to have been too rapid to permit such accumulation; but since the channel southeast of Sandy Hook was submerged, a bar rising from 19 fathoms to 4 fathoms below present mean sea level has been built up. By Mr. Lindenkohl's computation, based on Professor Cook's estimate that the present rate of subsidence of the coast of New Jersey is about two feet in a hundred years, this bar represents a period of 4,500 years; but the average subsidence may have been slower, allowing a considerably longer time.

Combining this testimony of oscillations of the land with the records of the Glacial period, whose terminal moraine, at the southern limit of the till and of glacial striæ and glacially transported bowlders, forms the range of hills called the backbone of Long island and thence reaches westward from the Narrows across Staten island and northern New Jersey, we find their relationship to be as follows: Shortly before the Ice age this area was greatly uplifted, holding an altitude a half mile or more above its present height long enough for the Hudson to cut its now submerged fiord, twenty-five miles long and three miles wide, in easily eroded sandy clays. This elevation into the cold upper strata of the atmosphere may well have been the direct cause of the accumulation of the Quaternary ice-sheet, which covered the northern half of the continent, forming the terminal moraines and other drift deposits. Beneath the ice-sheet, however, the land was depressed until, when the ice finally melted away, much of the coast stood lower than now, as shown by fossiliferous marine beds overlying the glacial drift in northern New England, New Brunswick, the valley of the St. Lawrence, about Hudson's bay, and in Labrador and Greenland. The amount of this depression increases from a few feet near Boston and Gloucester, Massachusetts, to 520 feet at Montreal, and 1,000 to 2,000 feet in Greenland and Grinnell Land. Though it was probably induced by the pressure of the ice-weight, it does not appear to have been

even approximately proportionate, upon certain parts of its area, to the thickness of the ice accumulation. The sea, after the retreat of the ice, extended over the basin of Lake Champlain and far up the St. Lawrence and Ottawa valleys, but no Quaternary marine beds are found about Lake Ontario nor thence westward. In the latitude of New York, channels of southward drainage from the terminal moraines of Long island, Martha's Vineyard, Nantucket and Cape Cod, crossing their frontal plains of modified drift and continuing beneath the sea, show that this part of the coast was higher when these moraines were formed than now; and, as no post-glacial marine beds are found there, we may infer that no subsequent sinking has at any time carried this tract below its present level. It therefore seems probable that while the ice-sheet was retreating from its terminal moraine on Staten island, past the Catskills and along the Hudson and Champlain valley, the elevation of the coastal plain outside the Narrows, doubtless still retaining a hundred feet or more of its formerly very great altitude above the sea, and the contemporaneous depression of the region toward the north, known to have been more than five hundred feet below the present sea level at Montreal, caused the Hudson valley from Manhattan island northward to be occupied by a lake, held in by the northern barrier of the receding ice-sheet, and outflowing to the sea over the now submerged plain off Sandy Hook. Since the departure of the ice, a see-saw movement, further depressing the mouth of the Hudson and again uplifting the country northward, has determined the present courses of drainage.

Returning to the fiord of the Saguenay, cut in the very hard Laurentian gneiss and granite, and comparing it with the shorter submerged fiord of the Hudson, cut in soft Tertiary clays, it is obvious that a much longer time was required for the erosion of the Saguenay gorge and the similar fiords of all the coast from Maine to Greenland, and also from the Columbia to Alaska; but still this work was not geologically very long, else these valleys would have become widened, being bordered by gentle slopes instead of steep fiord walls. Professor Hitchcock has called attention to the general absence of Tertiary formations along these northern shores of our continent as proof that the land was higher than now throughout the whole Tertiary era. No coastal Pliocene formations are known north of the Carolinas. Thence to the Arctic ocean the present land surface seems to have been nowhere submerged during the Pliocene period; but, on the contrary, evidence of great elevation is afforded by the stream-eroded indentations of Pamlico and Albemarle sounds and Chesapeake and Delaware bays, while the vastly older northern coasts are sharply incised by the deep but narrow fiords. This erosion was probably effected during a period of extraordinary elevation, when the northern part of this continent was uplifted as a plateau much above its previous or present height; and this uplift seems to have occurred earlier and to have lasted longer in far northern latitudes than in the vicinity of New York. The Hudson fiord indicates that it culminated near the close of the Pliocene period, initiating the Quaternary glaciation.

In the interior of the continent, evidence of similar preglacial elevation and of depression during the Glacial period is afforded by the basins of the great Laurentian lakes. The origin and history of these basins have been well studied by Newberry, Claypole, Spencer, Drummond, and others. In the light of their investigations let us trace briefly the geologic records of the oscillations of this area:

The very great disturbances of the region on the west in elevation of the Cordilleran mountain ranges, since the Cretaceous period, make it impossible to identify there the course of the larger tributaries to the mediterranean Cretaceous sea which stretched from the Gulf of Mexico to the latitude of Athabasca and Great Slave

lakes; but on the eastern half of the continent the principal drainage system, carrying its vast freight of detritus west to the Cretaceous ocean, is probably marked by the chain of great lakes from Ontario to Superior, the west end of which is close to the east border of the Cretaceous belt. At that time and afterward much of this eastern land area was elevated at least several hundred feet above its present level, so that streams flowing where these great lakes now are, eroded their basins, then lying wholly above the sea level and sloping westward. It seems possible also that other great tributaries may have flowed west and south into this Cretaceous sea, bringing sediments eroded from the areas of Hudson's bay, Lake Athabasca, and Great Slave and Great Bear lakes. Amid the subsequent changes of level which have permanently uplifted the Cretaceous sea-bottom in the center of the continent, and have uplifted and afterward depressed our northern coasts, both on the Atlantic and the Pacific, the writer believes that the basins of the Laurentian lakes, while still continuous areas of valley erosion, were raised with the country east and west to a great altitude for a short time at the end of the Pliocene period, as shown by deep stream-courses enveloped by the drift deposits, but that in the Quaternary depression, by differential subsidence, these basins became divided from each other, their bottoms, excepting that of Lake Erie, sinking beneath the level of the sea. The avenue of outflow from them has been turned to the northeast, forming the River St. Lawrence, in the Glacial period. President Chamberlin believes that much subsidence of the beds of these lakes probably is attributable to the weight of the ice-sheet. The post-glacial re-elevation, which has produced the northward ascent of the beaches of the glacial Lake Agassiz and of the contemporaneous higher stages of the Laurentian lakes, has failed to raise these lake beds, as likewise the bottoms of the fiords, to the present sea level.

The next paper was presented in abstract only, and follows in brief synopsis:

ON THE GENUS SPIRIFERA, AND ITS INTERRELATIONS WITH THE GENERA SPIRIFERINA, SYRINGOTHYRIS, CYRTIA AND CYRTINA.

BY JAMES HALL.

[*Synopsis.*]

1. Great development of *Spirifera* in American Paleozoic.
2. Previous classification of species.
3. External ornamentation as a basis of classification.

NORMAL FORMS.

(*A*) *radiata*
(*B*) *lamellosa*
(*C*) *fimbriata*
fimbriata-plicata } *reticularia*, McCoy.
" *undulata*
} Begin in the Niagara.

ABERRANT FORMS.

(*D*) *lævis*. Begins in the Corniferous.
Ambocœlia differs internally.

(*E*) *medio-plicata*. Begins in the Oriskany.

a) Forms of sub-circular or elongate outline—*S. hungerfordi*.

b) Forms in which plications are few and strong—*S. keokuk*.

c) Forms in which plications are in fascicles—*S. camerata*.

(*F*) *medio-lævis*, or *Syringothyris* group. Begins in the Corniferous.

The *radiata*, *fimbriata*, and *medio-plicata* are without essential variation in spiriferoid character.

lævis: slightly variable in development of dental lamellæ.

lamellosa: septate or non-septate. The septate group begins in the Niagara, is continued through the lower Helderberg, Corniferous, Hamilton and Kinderhook; the shell remaining impunctate.

Results in *Spiriferina*.

Where does punctation begin?

medio-lævis: Gradual development of apical callosity, *Syringothyris* tube, high area, etc.

Homologous structure in *Cyrtina*.

Incipient punctation in *Syringothyris*.

Cyrtina: In external expression usually in harmony with *medio-lævis*.

Cyrtia: Like *Cyrtina* on outside; differs from *Spirifera* only in the development of the dental lamellæ.

The next paper was entitled:

ON THE METAMORPHIC ROCKS OF SOUTHEASTERN NEW YORK.

BY F. J. H. MERRILL.

It led to a discussion in which C. R. Van Hise, B. K. Emerson, C. H. Hitchcock, and J. E. Wolff took part.

The remaining paper was read by title, in the absence of the author:

ON POT-HOLES NORTH OF LAKE SUPERIOR UNCONNECTED WITH EXISTING STREAMS.

BY PETER MCKELLAR, F. G. S.

In 1874 my brother Donald McKellar discovered a large pot-hole in hornblende rock about 1½ miles back from McKellar harbor, northeast of the Slate islands, on the north shore of Lake Superior.

I examined the locality and found about fifty similar holes, with diameters varying from a couple of feet up to more than thirty feet. Some are quite round, smooth, and well defined; others are oblong, some of which appear to result from coälescence of two or more holes. These holes occur on the east side of a steep mountain, and show on the different ledges from the bottom up to within a few feet of the summit. The western or mountain side of many of the holes stands up above the front side, in some cases as much as thirty feet or more. In general these holes are filled up, or nearly so, with such materials as bowlders, gravel, sand, black muck and water, but some are empty down for many feet. Their depths are unknown, as in no case has the bottom of any been reached or exposed, although in several instances a pole has been shoved down in the peaty bottom for several feet.

The original pot-hole area was, most probably, much larger than it is now, as much erosion of the mountain and vicinity seems to have taken place since the formation of these holes. An area 200 by 400 feet would, I think, cover what now remains of the perforated surface. Further examination may discover many more pot-holes here, as portions are under cover of drift, alluvium and vegetable matter.

The mountain is about 200 feet high, and at its base on the southeast side is a small lake or pond ten or twelve acres in extent. When viewing the situation I was impressed with the idea that these pot-holes are the work of a great stream, and that this little lake is the chief pot-hole or pool into which the mighty fall of water plunged; these seem the only traces left of that stream of the long past ages. I named the mountain Pot-hole mountain, and the lake Pot-hole lake.

In the following notes of a number of the pot-holes, the measurements are approximate estimates made on the ground and not exact measurements.

No. 1. The pot-hole is at an elevation of 150 to 200 feet above, and lies 100 to 150 feet to the west of Pot-hole lake. It is double; shorter diameter, 16 feet; longer, 30 feet. Wall, smooth and vertical, rises above the black muck filling, to the west 20 feet, to the north 6 feet, and to the east 2 feet.

No. 2. The pot-hole is 6 feet in diameter, lies 40 feet to the eastward of and 8 feet below no. 1. The western wall is elevated 4 feet above the eastern.

No. 3. 5 by 6 feet in diameter, lies 15 feet north of no. 1. The back or western wall rises above the filling and the front portion of wall about 12 feet.

No. 4. 4 by 5 feet in diameter; lies from no. 1, N. 16° E. 120 feet. The western wall rises 30 feet above the filling and the front.

No. 5. 6 feet lower than no. 4. It is sub-triangular, with the sides 10 feet each. The wall rises to the north 10 to 20 feet, with an inclination of 85°; to the southwest 25 feet; to the southeast 6 feet; and to the east 3 feet.

No. 6. 5 feet lower and 8 feet to the east of no. 5. The wall rises above filling, to the north 1½ feet, to the east 1 foot, to the south 4 feet, and to the west 5 feet.

No. 7. 5 feet above and 3 feet northeast of no. 5. It is round and smooth, filled with black muck.

No. 8. 7 feet to the northeast of and 10 feet lower than no. 5. It is 17 feet in diameter, with the wall rising to the northeast 3 feet; to the north 10 feet; to the northwest 20 feet; to the southwest 7 feet; and to the east 1 foot.

No. 9. 4 feet lower than and 10 feet east-northeast of no. 8. Its diameter is 8 by 10 feet, increasing in size downwards. The wall rises about 5 feet above the earthy filling all around.

No. 10. 20 by 60 feet in diameter, filled with bowlders, earth, etc.

No. 11. 4 feet in diameter, with a portion of the wall rising 10 feet.

No. 12. 6 by 10 feet in diameter. The wall rises to the west 16 feet; to the north and the south about 8 feet. There are two small pot-holes in the top of the wall, with diameters of 2 and 3 feet respectively.

No. 13. 6 feet in diameter. The wall is smooth and rises in places to the height of about 8 feet; another hole 3 feet in diameter is distant 2 feet to the east and is 6 feet lower.

No. 14. 12 feet northeast of and 8 feet lower than no. 13.

No. 15. 6 feet in diameter. Lies 8 feet to the southeast of and is 10 feet lower than no. 8. The wall is low to the east, 18 feet high to the south and the southwest, and 11 feet to the northward.

No. 16. 12 feet east of and 8 feet lower than no. 15.

No. 17. 16 by 25 feet in diameter. The wall between it and no. 13 stands up 4 feet above the filling, with a thickness of only 2 feet.

No. 18. 6 by 10 feet in diameter; 26 feet southwest of and 10 feet higher than no. 5.

No. 19. The west wall rises 30 feet.

No. 20. 5 feet in diameter, and its wall rises 3 to 4 feet.

The Twin pot-holes are situated near the edge of a cliff of rock and about 20 to 30 feet below the summit of the mountain, and are immediately west of and about 60 feet above pot-hole no. 17 in the foregoing list. The two holes are round and smooth and 6 to 7 feet each in diameter. In going down they join at a depth of 10 to 12 feet, and within a yard or so of the earthy bottom. About the point where the two join, the one on the south side has broken an opening 2 to 3 feet by 4 to 5 feet in diameter out into the face of the steep cliff. I descended to the bottom with a sharpened pole and forced it down into the soft peaty bottom several feet without reaching the solid rock.

Pot-hole mountain is composed of a dark green hornblende rock, with a small percentage of greenish white feldspar. It is hard and tough, and shows a fibrous structure. It forms one of the strata of the green Huronian schists which occupy the locality. These strata dip to the N. N. W. at a high angle.

The surface of the surrounding country is rough and rocky by reason of the numerous coalescing valleys, with oblong hills often steep and bare, and rising 50 to over 200 feet above them. The general level of the bottoms of these valleys rises irregularly back from Lake Superior, and gains an elevation of probably 300 feet at Pot-hole lake. Pot-hole mountain is one of the highest knobs in the locality. It is surrounded by a deep valley near by, and in the distance by similar knobs and valleys, especially towards the northwestward, the direction from which the stream that produced the pot-holes seems to have flowed. When this stream was in action the valleys to the northwestward must have been filled with rock, earth, or ice to carry the stream. Since then the locality has been eroded and a vast amount of material swept away. In one place horizontal glacial grooves may be seen on a portion of the elevated, vertical wall of the pot-hole. The action of the water is evident everywhere. Terraces show at higher elevations than Pot-hole mountain, in the neighborhood and along Lake Superior.

In conclusion, I would state that it seems to me that the currents that produced these pot-holes existed prior to the Champlain or even the close of the Drift epoch, if not prior to the beginning of the latter.

The retiring President, Professor James Hall, gave a farewell address. The Society then adjourned to meet at Indianapolis on Tuesday, August 19, 1890, at 10 A. M.

CONSTITUTION AND BY-LAWS OF THE GEOLOGICAL SOCIETY OF AMERICA.

CONSTITUTION.

PREAMBLE.

The Fellows of The Geological Society of America, organized under the provisions of the Constitution approved at Cleveland, Ohio, August 15, 1888, and adopted at Ithaca, New York, December 27, 1888, hereby ordain the following revised Constitution:

ARTICLE I.—NAME.

This Society shall be known as THE GEOLOGICAL SOCIETY OF AMERICA.

ARTICLE II.—OBJECT.

The object of this Society shall be the promotion of the Science of Geology in North America.

ARTICLE III.—MEMBERSHIP.

SECTION 1. The Society shall be composed of Fellows, Correspondents, and Patrons.

SEC. 2. Fellows shall be persons who are engaged in geological work or in teaching geology, and resident in North America.

Fellows admitted without election, under the PROVISIONAL CONSTITUTION, shall be designated as ORIGINAL FELLOWS on all lists or catalogues of the Society.

SEC. 3. Correspondents shall be persons distinguished for their attainments in geological science, and not resident in North America.

SEC. 4. Patrons shall be persons who have bestowed important favors upon the Society.

SEC. 5. Fellows alone shall be entitled to vote or hold office in the Society.

ARTICLE IV.—OFFICERS.

SEC. 1. The *Officers* of the Society shall consist of a President, First and Second Vice-Presidents, a Secretary, a Treasurer, and six Councilors.

These officers shall constitute an Executive Committee, which shall be called the *Council.*

SEC. 2. The *President* shall discharge the usual duties of a presiding officer at all meetings of the Society and of the Council. He shall take cognizance of the acts of the Society and of its officers, and cause the provisions of the Constitution and By-Laws to be faithfully carried into effect.

SEC. 3. The *First Vice-President* shall assume the duties of President in case of the absence or disability of the latter. The *Second Vice-President* shall assume the duties of President in case of the absence or disability of both the President and First Vice-President.

SEC. 4. The *Secretary* shall keep the records of the proceedings of the Society, and a complete list of the Fellows, with the dates of their election and disconnection with the Society. He shall also be the Secretary of the Council.

The *Secretary* shall co-operate with the President in attention to the ordinary affairs of the Society. He shall attend to the preparation, printing, and mailing of circulars, blanks, and notifications of elections and meetings. He shall superintend other printing ordered by the Society or by the President, and shall have charge of its distribution under the direction of the Council.

The *Secretary*, unless other provision be made, shall also act as *Editor* of the publications of the Society, and as *Librarian* and *Custodian* of the property.

SEC. 5. The *Treasurer* shall have the custody of all funds of the Society. He shall keep an account of receipts and disbursements in detail, and this shall be audited as hereinafter provided.

SEC. 6. The Society may elect an *Editor*, to supervise all matters connected with the publication of the transactions of the Society under the direction of the Council, and to perform the duties of Librarian until such time as, in the opinion of the Council, the Society should make that an independent office.

SEC. 7. The *Council* is clothed with executive authority, and with the legislative powers of the Society in the intervals between its meetings; but no extraordinary act of the Council shall remain in force beyond the next following stated meeting, without ratification by the Society. The Council shall have control of the publications of the Society, under provisions of the By-Laws and of resolutions from time to time adopted. They shall receive nominations for Fellows, and on approval by them shall submit such nominations to the Society for action. They shall have power to fill vacancies *ad interim* in any of the offices of the Society.

SEC. 8. *Terms of Office.*—The President and Vice-Presidents shall be elected annually, and shall not be eligible to re-election more than once until after an interval of three years after retiring from office.

The Secretary and Editor shall be eligible to re-election without limitation.

The term of office of the Councilors shall be three years ; and these officers shall be so grouped that two shall be elected and two retire each year. Councilors retired shall not be re-eligible till after the expiration of a year.

ARTICLE V.—VOTING AND ELECTIONS.

SEC. 1. All *elections* shall be by ballot. To elect a Fellow, Correspondent, or Patron, or to impose any special tax shall require the assent of nine-tenths of all Fellows voting.

SEC. 2. Voting by *letter* may be allowed.

SEC. 3. *Election of Fellows.*—Nominations for fellowship may be made by two Fellows, according to a form to be provided by the Council. One of these Fellows must be personally acquainted with the nominee and his qualifications for membership. The Council will submit the nominations received by them, if approved, to a vote of the Society in the manner provided in the By-Laws. The result may be announced at any stated meeting ; after which notices shall be sent out to Fellows elect.

SEC. 4. *Election of Officers.*—Nominations for office shall be made by the Council. The nominations shall be submitted to a vote of the Society in the same manner as nominations for fellowship. The results shall be announced at the Annual Meeting ; and the officers thus elected shall enter upon duty at the adjournment of the meeting.

ARTICLE VI.—MEETINGS.

SEC. 1. The Society shall hold at least two stated meetings a year—a *Summer Meeting,* at the same locality and during the same week as the annual meeting of the American Association for the Advancement of Science, and a *Winter Meeting.* The date and place of the Winter Meeting shall be fixed by the Council, and announced by circular each year within a month after the adjournment of the Summer Meeting. The programme of each Meeting shall be determined by the Council, and announced beforehand, in its general features. The details of the daily sessions shall also be arranged by the Council.

SEC. 2. The Winter Meeting shall be regarded as the *Annual Meeting.* At this, elections of Officers shall be declared, and the officers elect shall enter upon duty at the adjournment of the Meeting.

SEC. 3. *Special Meetings* may be called by the Council, and must be called upon the written request of twenty Fellows.

SEC. 4. *Stated Meetings of the Council* shall be held coincidently with the Stated Meetings of the Society. Special meetings may be called by the President at such times as he may deem necessary.

SEC. 5. *Quorum.*—At meetings of the Society a majority of those registered in attendance shall constitute a quorum. Five shall constitute a quorum of the Council.

ARTICLE VII.—PUBLICATION.

The serial publications of the Society shall be under the immediate control of the Council.

ARTICLE VIII.—AMENDMENTS.

SEC. 1. This Constitution may be amended at any annual meeting by a three-fourths vote of all the Fellows, provided that the proposed amendment shall have been submitted in print to all Fellows at least three months previous to the meeting.

SEC. 2. By-Laws may be made or amended by a majority vote of the Fellows present and voting at any annual meeting, provided that printed notice of the proposed amendment or By-Law shall have been given to all Fellows at least three months before the meeting.

BY-LAWS.

CHAPTER I.—OF MEMBERSHIP.

SEC. 1. No person shall be accepted as a Fellow unless he pay his initiation fee, and the dues for the year, within three months after ratification of his election. The initiation fee shall be ten (10) dollars and the annual dues ten (10) dollars, the latter payable on or before the annual meeting, in advance; but a single prepayment of one hundred (100) dollars shall be accepted as commutation for life.

SEC. 2. The sums paid in commutation of dues shall be invested and the interest used for ordinary purposes of the Society during the payer's life, but after his death the sum shall be covered into the Publication Fund.

SEC. 3. An arrearage in payment of annual dues shall deprive a Fellow of the privilege of taking part in the management of the Society, and of receiving the publications of the Society. An arrearage continuing over two (2) years shall be construed as notification of withdrawal.

SEC. 4. Any person eligible under Article III of the Constitution may be elected Patron upon the payment of one thousand (1,000) dollars to the Publication Fund of the Society.

CHAPTER II.—Of Officials.

Sec. 1. The *President* shall countersign, if he approves, all duly authorized accounts and orders drawn on the Treasurer for the disbursement of money.

Sec. 2. The *Secretary*, until otherwise ordered by the Society, shall perform the duties of Editor, Librarian, and Custodian of the property of the Society.

Sec. 3. The Society may elect an *Assistant Secretary*.

Sec. 4. The *Treasurer* shall give bonds, with two good sureties approved by the Council, in the sum of FIVE THOUSAND dollars, for the faithful and honest performance of his duties, and the safe-keeping of the funds of the Society. He may deposit the funds in bank at his discretion, but shall not invest them without authority of the Council. His accounts shall be balanced as on the thirtieth day of November of each year.

Sec. 5. In the selection of Councilors the various sections of North America shall be represented as far as practicable.

Sec. 6. The minutes of the proceedings of the Council shall be subject to call by the Society.

CHAPTER III.—Of Election of Members.

Sec. 1. Nominations for fellowship may be proposed at any time on blanks to be supplied by the Secretary.

Sec. 2. The *form* for the nomination of Fellows shall be as follows:

In accordance with his desire, we respectfully nominate for Fellow of the Geological Society of America:

(Full name)

(Address)

(Occupation)

(Branch of Geology now engaged in, work already done, and publications made)

(Degrees, if any)

(Signed by at least two fellows)

The form when filled is to be transmitted to the Secretary.

Sec. 3. The Secretary shall bring all nominations before the Council, at either the Winter or Summer Meeting of the Society, and the Council shall signify its approval or disapproval of each.

Sec. 4. At least a month before one of the stated meetings of the Society, the Secretary shall mail a printed list of all approved nominees to each Fellow,

accompanied by such information as may be necessary for intelligent voting. But an informal list of the candidates shall be sent to each fellow at least two weeks prior to distribution of the ballots.

SEC. 5. The Fellows receiving the list will signify their approval or disapproval of each nominee, and return the lists to the Secretary.

SEC. 6. At the next stated meeting of the Council the Secretary shall present the lists, and the Council shall canvass the returns.

SEC. 7. The Council, by unanimous vote of the members in attendance, may still exercise the power of rejection of any nominee whom new information shows to be unsuitable for fellowship.

SEC. 8. At the next stated meeting of the Society the Council shall declare the results.

SEC. 9. Correspondents and Patrons shall be nominated by the Council, and shall be elected in the same manner as Fellows.

CHAPTER IV.—OF ELECTION OF OFFICERS.

SEC. 1. The Council shall designate three candidates for each office.

SEC. 2. The *form* for the nomination and election of officers, unless otherwise provided by the Council, shall be as follows:

The Council nominates for Officers of the Geological Society of America, for the ensuing year, the following persons:

(The voter will indicate his preference out of each of the sets of names below by erasing the two other names in each set, or will substitute the name of his choice.)

For President,	1. 2. 3.
For First Vice-President,	1. 2. 3.
For Second Vice-President,	1. 2. 3.
For Secretary,	1. 2. 3.
For Treasurer,	1. 2. 3.

For Councilor, { 1.
2.
3. }

For Councilor, { 1.
2.
3. }

The Secretary shall mail a copy of this ballot to each Fellow, who after making up the list will return it to the Secretary.

SEC. 3. At the winter meeting of the Council, the Secretary shall bring the returns of ballots before the Council for canvass, and during the winter meeting of the Society the Council shall declare the results.

SEC. 4. In case a majority of all the ballots shall not have been cast for any candidate for any office, the Society shall by ballot at such winter meeting proceed to make an election for such office from the two candidates having the highest number of votes.

CHAPTER V.—OF FINANCIAL METHODS.

SEC. 1. No pecuniary obligation shall be contracted without express sanction of the Society or the Council. But it is to be understood that all ordinary, incidental and running expenses have the permanent sanction of the Society, without special action.

SEC. 2. The creditor of the Society must present to the Treasurer a fully *itemized* bill, *certified* by the official ordering it, and *approved* by the President. The Treasurer shall then pay the amount out of any funds not otherwise appropriated, and the receipted bill shall be held as his voucher.

SEC. 3. At each annual meeting, the President shall call upon the Society to choose two Fellows, not members of the Council, to whom shall be referred the books of the Treasurer, duly posted and balanced to the close of November thirtieth, as specified in the By-Laws, Chapter II, Section 4. The *Auditors* shall examine the accounts and vouchers of the Treasurer, and any member or members of the Council may be present during the examination. The report of the Auditors shall be rendered to the Society before the adjournment of the meeting, and the Society shall take appropriate action.

CHAPTER VI.—OF PUBLICATIONS.

SEC. 1. The Publications are in charge of the Council and under its control.

SEC. 2. One copy of each publication shall be sent to each Fellow, Correspondent, and Patron, and each author shall receive thirty (30) copies of his memoir.

CHAPTER VII.—Of the Publication Fund.

Sec. 1. The Publication Fund shall consist of moneys paid by the general public for publications of the Society, of donations made in aid of publication, and of the sums paid in commutation of dues, according to the By-Laws, Chapter I, Section 2.

Sec. 2. Donors to this fund, not Fellows of the Society, in the sum of two hundred dollars, shall be entitled without charge, to the publications subsequently appearing.

CHAPTER VIII.—Of Order of Business.

Sec. 1. The order of Business at *Annual Meetings* shall be as follows:

(1) Call to order by the Presiding Officer.
(2) Introductory ceremonies.
(3) Statements by the President.
(4) Report of the Council.
(5) Report of the Treasurer, and appointment of the Auditing Committee.
(6) Declaration of the results of the ballot for officers of the next ensuing Administration.
(7) Declaration of the results of the ballot for new Fellows.
(8) Announcement of the hour and place for the Address of the last ex-President.
(9) Necrological notices.
(10) Miscellaneous announcements.
(11) Business motions and resolutions and disposal thereof.
(12) Reports of committees and disposal thereof.
(13) Miscellaneous motions and resolutions.
(14) Presentation of memoirs.

Sec. 2. At an *adjourned session*, the order shall be resumed at the place reached on the previous adjournment, but new announcements, motions, and resolutions will be in order before the resumption of the business pending at the adjournment of the last preceding session.

Sec. 3. At the *Summer Meeting* the items of business under numbers (4), (5), (6), (8), (9) shall be omitted.

Sec. 4. At any *Special Meeting* the Order of Business shall be (1), (2), (3), (7), (10), followed by the special business for which the meeting was called.

LIST OF

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA.

OFFICERS FOR 1889.

James Hall, *President.*
James D. Dana, } *Vice-Presidents.*
Alexander Winchell, }
John J. Stevenson, *Secretary.*
Henry S. Williams, *Treasurer.*
John S. Newberry, }
J. W. Powell, } *Members-at-large of the Council.*
Chas. H. Hitchcock, }

FELLOWS.

Original Fellows.

1. Charles C. Abbott, M. D., Trenton, N. J.
2. Charles A. Ashburner, M. S., C. E., Pittsburgh, Pa. (Died December 24, 1889.)
3. George. F. Becker, Ph. D., San Francisco, Cala.; U. S. Geological Survey.
4. John C. Branner, Ph. D., Little Rock, Ark.; State Geologist of Arkansas.
5. Garland C. Broadhead, Columbia, Mo.; Professor of Geology in the University of Missouri.
6. Samuel Calvin, Iowa City, Iowa; Professor of Geology and Zoölogy in the State University of Iowa.
7. Thomas C. Chamberlin, LL. D., Madison, Wis.; President of the University of Wisconsin.
8. J. H. Chapin, Ph. D., Meriden, Conn.; Professor in St. Lawrence University.
9. William B. Clark, Ph. D., Baltimore, Md.; Instructor in Geology in Johns Hopkins University.
10. Edward W. Claypole, D. Sc., Akron, Ohio; Professor of Geology in Buchtel College.
11. John Collett, M. D., Indianapolis, Ind.; State Geologist of Indiana.
12. Theodore B. Comstock, Austin, Tex; Geological Survey of Texas.
13. George H. Cook, Ph. D., LL. D., State Geologist; Professor of Geology in Rutgers College. (Died September 22, 1889.)
14. Edward D. Cope, Ph. D., 2102 Pine St., Philadelphia; Professor of Geology in the University of Pennsylvania.

15. Francis W. Cragin, B. S., Topeka, Kansas; Professor of Geology and Natural History in Washburne College.
16. Albert R. Crandall, A. M., Lexington, Kentucky; Professor of Geology in Agricultural and Mechanical College of Kentucky.
17. William O. Crosby, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.
18. Malcolm H. Crump, Bowling Green, Kentucky; Professor of Natural Science in Ogden College.
19. Henry P. Cushing, M. S., 786 Prospect St., Cleveland, Ohio.
20. James D. Dana, LL. D., New Haven, Conn.; Professor of Geology in Yale University.
21. Nelson H. Darton, United States Geological Survey, Washington, D. C.
22. William M. Davis, Cambridge, Mass.; Professor of Physical Geography in Harvard University.
23. Joseph S. Diller, B. S., United States Geological Survey, Washington, D. C.
24. William B. Dwight, M. A., Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.
25. George H. Eldridge, A. B., United States Geological Survey, Washington, D. C.
26. Benjamin K. Emerson, Ph. D., Amherst, Mass.; Professor of Geology in Amherst College.
27. Samuel F. Emmons, A. M., E. M., United States Geological Survey, Washington, D. C.
28. Herman L. Fairchild, B. S., Rochester, N. Y.; Professor of Geology and Natural History in University of Rochester.
29. Albert E. Foote, M. D., 1223 Belmont Ave., Philadelphia, Pa.
30. P. Max Foshay, A. B., Beaver Falls, Pa.
31. Persifor Frazer, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Franklin Institute.
32. Homer T. Fuller, Ph. D., Worcester, Mass.; Professor of Geology in Worcester Polytechnic Institute.
33. Grove K. Gilbert, A. M., United States Geological Survey, Washington, D. C.
34. George B. Grinnell, Ph. D., 318 Broadway, N. Y. City.
35. William F. E. Gurley, Danville, Illinois,
36. Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.
37. James Hall, LL. D., State Hall, Albany, N. Y.; State Geologist and Director of the State Museum.
38. Erasmus Haworth, Ph. D., Oskaloosa, Iowa; Professor of Natural Sciences in Penn College.
39. Robert Hay, Box 162, Junction City, Kansas.
40. Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.
41. Lewis E. Hicks, Lincoln, Nebraska; Professor of Geology in the University of Nebraska.
42. Eugene W. Hilgard, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

43. ROBERT T. HILL, B. S., Austin, Texas; Professor of Geology in University of Texas.
44. CHARLES H. HITCHCOCK, Ph. D., Hanover, N. H.; Professor of Geology in Dartmouth College.
45. LEVI HOLBROOK, A. M., P. O. Box 536, N. Y. City.
46. JOSEPH A. HOLMES, Chapel Hill, North Carolina; Professor of Geology in University of North Carolina.
47. JEDEDIAH HOTCHKISS, 346 E. Beverly St., Staunton, Virginia.
48. EDMUND O. HOVEY, Ph. D., Waterbury, Conn.
49. HORACE C. HOVEY, D. D., 14 Park St., Bridgeport, Conn.
50. EDWIN E. HOWELL, A. M., 18 College Ave., Rochester, N. Y.
51. ALPHEUS HYATT, B. S., Bost. Soc. of Nat. Hist., Boston, Mass.; Curator of Boston Society of Natural History.
52. JOSEPH F. JAMES, M. S., United States Geological Survey, Washington, D. C.
53. LAWRENCE C. JOHNSON, United States Geological Survey, Meridian, Miss.
54. W. D. JOHNSON, United States Geological Survey, Washington, D. C.
55. JAMES F. KEMP, A. B., E. M., Ithaca, N. Y.; Assistant Professor of Geology and Mineralogy in Cornell University.
56. GEORGE F. KUNZ, 402 Garden St., Hoboken, N. J.
57. JOSEPH LECONTE, M. D., LL. D., Berkeley, Cal.; Professor of Geology in the University of California.
58. J. PETER LESLEY, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.
59. W J MCGEE, United States Geological Survey, Washington, D. C.
60. FREDERICK J. H. MERRILL, Ph. B., Fordham Heights, N. Y. City.
61. ALBRO D. MORRILL, A. M, M. S., Athens, Ohio; Professor of Biology and Geology in Ohio University.
62. FRANK L. NASON, A. B., 5 Union St., New Brunswick, N. J.; Assistant on Geological Survey of New Jersey.
63. HENRY B. NASON, Ph. D., M. D., LL. D., Troy, N. Y.; Professor of Chemistry and Natural Science in Rensselaer Polytechnic Institute.
64. PETER NEFF, A. M., 401 Prospect St., Cleveland, Ohio.
65. JOHN S. NEWBERRY, M. D., LL. D., Columbia College, N. Y. City; Professor of Geology and Paleontology in Columbia College.
66. EDWARD ORTON, Ph. D., LL. D., Columbus, Ohio; State Geologist and Professor of Geology in the State University.
67. AMOS O. OSBORN, Waterville, Oneida Co., N. Y.
68. RICHARD OWEN, LL. D., New Harmony, Ind. (Died March 24, 1890.)
69. HORACE B. PATTON, Ph. D., New Brunswick, N. J.; Assistant Professor of Geology and Mineralogy in Rutgers College,
70. WILLIAM H. PETTEE, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology, and Mining Engineering in Michigan University.
71. FRANKLIN PLATT, 615 Walnut St., Philadelphia, Pa.
72. JULIUS POHLMAN, M. D., Buffalo Society of Natural Sciences, Buffalo, N. Y.
73. JOHN W. POWELL, Director of U. S. Geological Survey, Washington, D. C.
74. JOHN R. PROCTER, Frankfort, Kentucky; State Geologist.
76. CHARLES S. PROSSER, M. S., U. S. National Museum, Washington, D. C.
77. EUGENE N. S. RINGUEBERG, M. D., Lockport, N. Y.
78. ISRAEL C. RUSSELL, M. S., United States Geological Survey, Washington, D. C.

79. JAMES M. SAFFORD, M. D., LL. D., Nashville, Tenn.; State Geologist; Professor in Vanderbilt University.
80. ROLLIN D. SALISBURY, A. M., Beloit, Wisconsin; Professor of Geology in Beloit College.
81. CHARLES SCHAEFFER, M. D., 1309 Arch St., Philadelphia, Pa.
82. NATHANIEL S. SHALER, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.
83. FREDERICK W. SIMONDS, Ph. D., Austin, Texas; Professor of Geology in University of Texas.
84. EUGENE A. SMITH, Ph. D., University, Tuscaloosa County, Ala.; Professor of Chemistry and Geology in University of Alabama.
85. JOHN C. SMOCK, Ph. D., State Museum, Albany, N. Y.; Assistant in Charge of the State Museum.
86. JOSEPH W. SPENCER, A. M., Ph. D., Athens, Georgia; State Geologist.
87. JOHN J. STEVENSON, Ph. D., University of the City of N. Y.; Professor of Geology in the University of the City of New York.
88. WILLIAM E. TAYLOR, Peru, Nemaha Co., Neb.; Teacher of Geology and Natural History in Nebraska State Normal School.
89. ASA SCOTT TIFFANY, 901 West Fifth St., Davenport, Iowa.
90. JAMES E. TODD, A. M., Tabor, Iowa; Professor of Natural Sciences in Tabor College.
91. HENRY W. TURNER, United States Geological Survey, Valley Springs, Cal.
92. EDWARD O. ULRICH, A. M., Newport, Kentucky.
93. WARREN UPHAM, A. B., 36 Newbury St., Somerville, Mass.; Assistant on the U. S. Geological Survey.
94. CHARLES R. VAN HISE, M. S., Madison, Wisconsin; Professor of Mineralogy and Petrography in Wisconsin University; Geologist, U. S. Geological Survey.
95. ANTHONY W. VOGDES, Fort Hamilton, N. Y. Harbor; Captain Fifth Artillery, U. S. Army.
96. MARSHMAN E. WADSWORTH, Ph. D., Houghton, Mich.; State Geologist; Director of Michigan Mining School.
97. CHARLES D. WALCOTT, U. S. National Museum, Washington, D. C.; Paleontologist, U. S. Geological Survey.
98. ISRAEL C. WHITE, Ph. D., Morgantown, W. Va.; Professor of Geology in West Virginia University.
99. ROBERT P. WHITFIELD, Ph. D., American Museum of Natural History, 77th St. and 8th Ave., N. Y. City; Curator of Geology and Paleontology in American Museum of Natural History.
100. EDWARD H. WILLIAMS, Jr., A. C., E. M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.
101. GEORGE H. WILLIAMS, Ph. D., Johns Hopkins University, Baltimore, Md.; Professor of Inorganic Geology in Johns Hopkins University.
102. HENRY S. WILLIAMS, Ph. D., Ithaca, N. Y.; Professor of Geology and Paleontology in Cornell University.
103. J. FRANCIS WILLIAMS, Ph. D., Salem, N. Y.
104. SAMUEL G. WILLIAMS, Ph. D., Ithaca, N. Y.; Professor in Cornell University.
105. ALEXANDER WINCHELL, LL. D., Ann Arbor, Mich.; Professor of Geology and Paleontology in Michigan University

106. HORACE VAUGHN WINCHELL, 10 State St., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota.
107. NEWTON H. WINCHELL, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.
108. ARTHUR WINSLOW, B. S., Jefferson City, Missouri; State Geologist.
109. G. FREDERICK WRIGHT, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.
110. CHARLES A. WHITE, M. D., U. S. National Museum, Washington, D. C.; Paleontologist, U. S. Geological Survey.
111. EDWIN T. DUMBLE, Austin, Texas; State Geologist.
112. WALTER A. BROWNELL, Ph. D., 905 University Avenue, Syracuse, N. Y.

Elected December 27, 1888.

113. JAMES E. MILLS, B. S., 2106 Van Ness Avenue, San Francisco, Cal.
114. HENRY G. HANKS, 1124 Greenwich St., San Francisco, Cal.; lately State Mineralogist.
115. EDWARD V. D'INVILLIERS, E. M., 711 Walnut St., Philadelphia, Pa.
116. WILLIAM M. FONTAINE, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia.
117. J. C. FALES, Danville, Kentucky; Professor in Centre College.
118. ADAMS C. GILL, A. B., Northampton, Mass.
119. JULES MARCOU, 42 Garden St., Cambridge, Mass.
120. WILLIAM S. BAYLEY, Ph. D., Waterville, Maine; Professor of Geology in Colby University.
121. A. WENDELL JACKSON, Ph. B., Berkeley, Cal.; Professor of Mineralogy, Petrography and Economic Geology in University of California.
122. GEORGE P. MERRILL, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology.
123. ROBERT W. ELLS, LL. D., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada.
124. JOSEPH H. PERRY, Worcester, Mass.; Professor of Natural Sciences in the Worcester High School.
125. P. H. MELL, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute.
126. DAVID HONEYMAN, D. C. L., Halifax, Nova Scotia; Provincial Geologist. (Died October 17, 1889.)

Elected May 20, 1889.

127. ROBERT BELL, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada.
128. CHARLES E. BEECHER, Ph. D., Yale University, New Haven, Conn.
129. RICHARD G. McCONNELL, A. B., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada.
130. JOSEPH B. TYRRELL, A. B., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada.

131. FRANK A. HILL, 208 S. Centre St., Pottsville, Pa.; Geologist in Charge of Anthracite District, 2d Geological Survey of Pennsylvania.
132. LESTER F. WARD, A. M., U. S. Geological Survey, Washington, D. C.; Paleontologist, U. S. Geological Survey.
133. FREDERICK P. DEWEY, Ph. B., Smithsonian Institution, Washington, D. C.; Curator of Department of Metallurgy, U. S. National Museum.
134. CHARLES WHITMAN CROSS, Ph. D., U. S. Geological Survey, Washington, D. C.
135. JOSEPH P. IDDINGS, Ph. B., U. S. Geological Survey, Washington, D. C.
136. ARNOLD HAGUE, Ph. B., U. S. Geological Survey, Washington, D. C.
137. OLIVER MARCY, LL. D., Evanston, Cook Co., Illinois; Professor of Natural History in Northwestern University.
138. Sir J. WILLIAM DAWSON, LL. D., McGill College, Montreal, Canada; Principal of McGill University.
139. MARY E. HOLMES, Ph. D., 201 S. First St., Rockford, Illinois.
140. THOMAS M. JACKSON, C. E., Morgantown, W. Va.; Professor of Civil and Mining Engineering in West Virginia University.
141. ROBERT H. LOUGHRIDGE, Ph. D., Columbia, South Carolina; Professor of Agricultural Chemistry in University of South Carolina.
142. FREDERICK H. NEWELL, B. S., U. S. Geological Survey, Washington, D. C.
143. CLARENCE KING, 18 Wall St., N. Y. City; lately Director of the U. S. Geological Survey.
144. ROBERT SIMPSON WOODWARD, C. E., U. S. Geological Survey, Washington, D. C.
145. MORITZ FISCHER, State Museum, Frankfort, Ky.; Assistant on State Geological Survey and Curator of State Museum.
146. HENRY M. SEELY, M. D., Middlebury, Vermont; Professor of Geology in Middlebury College.
147. CHARLES WACHSMUTH, M. D., Burlington, Iowa.
148. FRANKLIN R. CARPENTER, Ph. D., Rapid City, South Dakota; Professor of Geology in Dakota School of Mines.
149. TRUMAN H. ALDRICH, M. E., 92 Southern Avenue, Cincinnati, Ohio.
150. ORESTES H. ST. JOHN, Topeka, Kansas.
151. RICHARD A. F. PENROSE, Jr., Ph. D., Little Rock, Arkansas; Assistant on Arkansas Geological Survey.
152. JOHN B. HASTINGS, M. E., Ketchum, Alturas Co., Idaho.
153. ROBERT CHALMERS, Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada.
154. CHARLES W. HAYES, Ph. D., U. S. Geological Survey, Washington, D. C.
155. HENRY MCCALLEY, A. M., C. E., University, Tuscaloosa County, Ala.; Assistant on Geological Survey of Alabama.
156. CHARLES W. ROLFE, M. S., Urbana, Champaign Co., Illinois; Professor of Geology in University of Illinois.
157. GEORGE M. DAWSON, D. Sc., A. R. S. M., Geological Survey Office, Ottawa, Canada; Assistant Director of Geological and Natural History Survey of Canada.
158. STEPHEN BOWERS, A. M., San Buena Ventura, California.
159. N. J. GIROUX, C. E., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada.

160. Clarence L. Herrick, M. S., 14 Mitchell Avenue, Mt. Auburn, Cincinnati, Ohio; Professor of Geology and Biology in the University of Cincinnati.
161. Samuel B. Howell, M. D., 1513 Green St., Philadelphia, Pa.; Professor of Mineralogy and Geology in University of Pennsylvania.
162. William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada.
163. Maurice Thompson, Crawfordsville, Indiana; lately State Geologist.
164. Frank H. Knowlton, M. S., U. S. National Museum, Washington, D. C.; Assistant Curator of Botany in U. S. National Museum.
165. Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C.
166. Thomas H. McBride, Iowa City, Iowa; Professor of Botany in the State University of Iowa.
167. David White, U. S. Geological Survey, Washington, D. C.
168. Frederick D. Chester, M. S., Newark, Delaware: Professor of Geology and Botany in Delaware College.
169. Alexis A. Julien, Ph. D., Columbia College, N. Y. City; Instructor in Columbia College.
170. P. J. Farnsworth, M. D., Clinton, Iowa; Professor in the State University of Iowa.
171. Othniel C. Marsh, Ph. D., LL. D., New Haven, Conn.; Professor of Paleontology in Yale College.
172. Thomas F. Moses, M. D., Urbana, Ohio; President of Urbana University.
173. Henry Donald Campbell, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University.
174. Walter H. Weed, M. E., U. S. Geological Survey, Washington, D. C.
175. Andrew C. Lawson, Ph. D., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada.
176. Amos Bowman, Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada.

Elected December 26, 1889.

177. George C. Swallow, M. D., LL. D., Helena, Montana; State Geologist; lately State Geologist of Missouri, and also of Kansas.
178. Albert S. Bickmore, Ph. D., American Museum of Natural History, 77th St. and 8th Avenue, N. Y. City; Curator of Anthropology in the American Museum of Natural History.
179. John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Instructor in Petrography, Harvard University.
180. Ezra Brainerd, LL. D., Middlebury, Vermont; President of Middlebury College.
181. Thomas Sterry Hunt, D. Sc., LL. D., Park Avenue Hotel, N. Y. City.
182. R. D. Lacoe, Pittston, Pa.
183. Aaron H. Cole, A. M., Hamilton, N. Y.; Lecturer on Natural History in Madison University.
184. Frank Dawson Adams, Montreal, Canada; Lecturer on Geology at McGill College.

185. Lorenzo G. Yates, M. D., Santa Barbara, California.
186. Henry M. Ami, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada.
187. Victor C. Alderson, 6721 Honore St., Englewood, Ills.
188. Alfred R. C. Selwyn, C. M. G., LL. D., Ottawa, Canada; Director of Geological and Natural History Survey of Canada.
189. Bailey Willis, U. S. Geological Survey, Washington, D. C.
190. Alfred C. Lane, Ph. D., Houghton, Michigan; Assistant on Geological Survey of Michigan.
191. Daniel W. Langdon, Jr., A. B., University Club, Cincinnati, Ohio; Geologist of Chesapeake and Ohio Railroad Co.

Summary.

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